Applied
FOOT ROENTGENOLOGY

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FELTON O. GAMBLE, D.S.C., F.A.S.C.R.

President, National Association of Chiropodists Formerly, Professor of Roentgenology, Temple University, School of Chiropody. Past President and Fellow, American Society of Chiropodical Roentgenology. Honorary Fellow, American Academy of Chiropody. Trustee, Alumni Association, Ohio College of Chiropody.

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Dedicated

to

MY PROFESSION

and

MY FAMILY

Preface

This monograph was written because there is need for a text on the roentgen study of patho–anatomic foot problems. If the roentgen observations are to be useful in clinical practice, it is obvious that the patho–anatomic patterns should be related to clinical problems; and this I have endeavored to do.

There is little in the literature to assist in such correlations, because radiographs of the weight–supporting foot were rarely used prior to the advent of shock-free equipment about 1920. Although the value of radiographs in diagnosing patho–anatomic foot problems was recognized by Kurtz in 1932, it was difficult to procure an erect–posture foot position radiograph, because of the necessity of a special apparatus. Cognizant of this need, I devised a suitable apparatus and embarked on an investigation that has led finally to this text.

My first report on the subject, in 1937, was based on several hundred cases encountered in practice. Since that time, thousands of cases have been observed from initial roentgen diagnosis through all phases of treatment. The present effort seeks to make this information generally available as a practical guide. I need hardly add that there is still much to learn about this relatively new field.

The text is didactic because I feel that detailed descriptions are warranted to explore the total foot status. Moreover, the book will supplant a set of *Lecture Notes on Foot Roentgenology* which I have used in teaching and which is also used as a syllabus in several colleges. No attempt has been made to include the interpretation of bone and joint pathology *per se*. This science is well documented by many splendid texts on the subject. The works of Yale and Lewis are of special interest to the foot specialist.

The roentgenologist will find in this text a new approach to foot problems—one that relates to specific faults rather than such generalities as "fallen arches." Each chapter in the first section develops a phase of interpretation. Part-by-part the foot is inspected and the several foot–types and problems are critically analyzed. The many illustrations may serve as pictorial condensations of the text for the benefit of the busy doctor. Moreover, the technique pictures may be used to train auxiliary personnel and constitute a complete and handy source manual for the trained technician.

The second section deals with office practice in order that foot roentgenology may be fully appreciated, in all its aspects, and properly administered. For the beginner, much basic information is provided.

Chapter XX, dealing with clinical applications, has some very practical applications of roentgenology in everyday practice. Radiography is very useful in evaluating such simple things as the realignment of the foot by adhesive taping, and the effect of various appliances and of various shoes.

I shall ever be grateful to Charles E. Krausz, Dean of the School of Chiropody

of Temple University for arranging my appointment to the faculty of that school. There I spent the years from 1937 to 1950, with opportunity for extensive clinical study and co-ordinated work in such related departments as those of anatomy and orthopedics.

Good friends have materially aided in the production of this book. Dr. William F. Eads has edited much of the scientific material presented. Dr. G. Elmer Harford, Professor of Anatomy, Temple University, School of Chiropody, has checked anatomical nomenclature and has performed many dissection projects of considerable interest. Mrs. E. J C. Twitchell has faithfully acted as a personal editor of the manuscript. Dr. Alan K. Whitney has done a sterling job of medical illustration through his drawings. Mr. William Taylor, medical photographer, Temple University Hospital has made the splendid facsimile radiographic reproductions and also photographed the technique series. My grateful thanks are offered for the years of indulgence shown by these people.

Tucson, Arizona FELTON O. GAMBLE

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Many people have been a source of inspiration and help in this work and I humbly acknowledge and memorialize, with great appreciation, their many favors: Dr. Barton R. Young, Dr. Bertram Kraus, Dr. E. L. Ruelhman, Dr. Harold Wheeler, Dr. M. Harmolin, Dr. W. A. Danielson, Dr. Arthur Rappaport, Dr. R. Willoughby, Dr. Gordon Rowe, Dr. Andrew Wish, Dr. Henri DuVries, Dr. Ralph Dye, Dr. P. H. Wells, Dr. Hubert Wells, Dr. William J. Stickel, Dr. L. A. Walsh, Miss C. F. Dyck, Mr. Harry Coulthard, Mr. E. J. Reis, Mr. A. J. Peterson, Mr. George Bierce, Mr. John Witaker, Mr. Warren G. Zapp, Mr. Jay Funston, and The Williams & Wilkins Company.

SECTION ONE

INTERPRETATION

Chapter I

Orthopedic Status of the Foot

For many centuries, there has been little change in the morphology of the human foot. The process of change through adaptation takes an immeasurable amount of time. We must accept the human foot in its present embodiment chiefly as our heritage and our own problem of comprehension.

It has been estimated that 7 out of 10 people incur foot difficulties at some period during their life. These failures of the feet to perform their intended functions fall into a number of categories. Traumatic problems are endless. A great number of talipedic disorders are involved. Acquired deformities, resulting from poliomyelitis, cerebral damage, and other injuries of the central and peripheral nervous systems, account for still another group of problems of management and correction.

However, the most common types of foot malfunctioning lack the dramatic effects imposed by the serious deformities just mentioned. The bulk of foot disorders may be said to exist because of patho-mechanical incompetence. It is unfortunate that little importance and even less understanding has been attached to this group of disorders. Foot patho-mechanics are complex. Loss of power in a single muscle of the foot can influence the entire gait and body mechanics of an individual. The physiological basis of foot action is profound. A study of some very simple considerations of the foot—considerations that too often are taken for granted—should lead to the conclusion that foot problems are extremely complex and that the foot is an intricate mechanism.

The foot performs the will of the muscles. The muscles, in turn, perform the will of the individual either to stand erect or to perform some phase of locomotion. The joints provide a variety of motions, each conditioned by the duty it must execute. Leverage arms, consisting of metatarsal bones, raise and lower the weight load in the act of locomotion. Toes, designed to dig in and make purchase, assist in propelling the body forward. During walking, the heel receives shock absorption, which is then transmitted in a smooth wave throughout the foot Running feet receive shock absorption in the forefoot and transmit it posteriorly The foot embodies the structural stability of a cantilevered building—maintaining a great amount of weight on a small base of support.

Feet are provided in pairs and achieve maximum effectiveness and economy through their design. The medial borders of the feet assume an arched structure

It likewise seems incongruous to ignore to any degree, or to de-emphasize, the complete dependence of the foot upon the muscular systems to make it effective in locomotion. The stabilizing effect of muscular tonus in the static attitude is also acknowledged.

Nature provides an essentially uniform foot structure. Atavistic bone shapes such as accessory, occasional, and vestigial bones, are throwbacks that occur infrequently. Embryonic defects of development such as over-segmentation, under-segmentation, and irregular segmentation, are acts of fate of little consequence in the over-all situation. We must accept a reasonable structural entity as a basis of distinction.

A comprehensive orthopedic consideration of the integrity of the foot should include not only all the features that have been discussed but the interrelations of all the anatomical systems as well. The complete physical status of the individual as to body type must be taken into account. The physical, mental and chronological age of the person is a factor. Extrinsic considerations, such as occupational attitudes of the body, work overloads leading to the threshold of fatigue, and related problems, should be investigated. Pathology affecting the individual profoundly affects the foot in many ways.

An apt clinician will utilize every diagnostic consideration in evaluating the status of foot orthopedic problems. The method developed by Frost is very comprehensive.

A GENERAL CLASSIFICATION OF FOOT COMPETENCE

By coordinating both the muscular system and the osseous system, including ligamentous integument, it is possible to develop practical definitions to describe different kinds of feet from the standpoint of general competence. The scope of definition embraces elements that should be included in any rational approach to the problem. The classification includes the normal foot, the abnormal foot, and the acceptable foot.

Normal Foot

A normal foot is a foot that maintains integrity through muscular equilibrium and presents an osseous pattern of stability.

An assessment of this definition should be simple. A normal foot is a strong foot. It gains its strength through a set of muscles that are superbly balanced with a set of foot bones that are of normal shape and alignment. A normal foot has the capacity to perform all motions with the full range and power needed for locomotion by the individual. In stance the normal foot assumes a characteristic anatomical conformity. Under radiographic examination the normal foot will satisfy a critical appraisal of bone shape and alignment.

Most authors offer orthopedic considerations of a normal foot in an extremely guarded manner. Some investigators deny that a normal foot is possible. Others use the term, "physiological limits," to define normalcy in such a loose way that the definition becomes impractical. It is, of course, true that normal feet are rare in clinical practice; the feet usually presented are faulty. Consequently, a misanthropic view can be developed. However, if an anthropometric study

extending to the great toes and take the central position in respect to the superimposed body as a whole. The heel bone takes the central position in relation to each individual foot. The lateral borders of the feet participate in the greatest area of weight support. The great toes are the most powerful factors in maintaining balance if the body falls forward Locomotion is a rhythmic action performing a cadence from one foot to the other. Inter-dependence of action is fundamental.

It is apparent that analysis of the above features: motivating forces, motion, leverage, weight, support, propulsion, shock absorption, structural stability, balance, and rhythmic action, pre-supposes a broad field of investigation in order to achieve a proper understanding of all patho-mechanical and patho-anatomical foot problems.

Investigations of the basic anatomical problems concerning the foot have been documented by many workers. The exhaustive work and applied genius of Duchenne, concerning physiology of motion, is classical and merits concentrated study. Spalteholz and numerous anatomists have affirmed every anatomical detail of the organs of locomotion.

A close study of the mechanical engineering problems involved must be made. Steindler, Schwartz, Morton, and others have explored patho-mechanical foot problems in this manner and their work is exemplary.

Research has been done on the subject of prenatal development and its pathological relation to foot weakness. The biochemical and electrochemical basis for muscle flaccidity, spasticity, and normal tone is under extended study. Wolff and Davis have supplied theories about structural changes related to use and function that are now accepted as laws. Wells, in his remarkable study, *The Foot of the South African Native,* has documented the adaptation of structure to the conditioning of environment. Information concerning footgear is a matter of record and much has been said about its effect on the foot.

The anthropologist has scientifically evaluated the entire gamut of the animal species in relation to the skeletal development of man. The erect posture of man has imposed special demands upon his pedal extremities. The extremities of quadruped animals cannot qualify for the same functions as those of *homo sapiens.* The adaptation of the human foot to locomotion exhibits a high degree of mechanical perfection. Occasionally, a vestigial variation is found that clearly indicates that the anthropologist has a valid basis for the chain of adaptive features he has so aptly postulated.

Opposing schools of thought have developed on the question of the competence of the human foot. The main area of contention seems to be over what is the relative importance of the inherent morphological framework, as compared to the value of the muscle system in maintaining stability. Although this theme has been presented in various forms, the argument is basically the same. Lake, for example, refuted Keith's views by demonstrating that ligaments preserve the integrity of the foot architecture when the muscles are rendered impotent.

It seems incomprehensible that the integrated morphology of the human foot should be discounted as the basic factor in maintaining the foot in a state of structural stability.

Instances of acceptable feet present an interesting cross-section. We have those of an idiopathic nature such as the spindle-legged person with frail muscular structure in which the foot structure is of excellent form and integrity because of the osseous pattern. At the other extreme is the case of a professional wrestling champion with a typical atavistic short first metatarsal. However, he exhibited a foot structure of excellent form because of strong musculature that acted as a safeguard and overcame any tendency toward foot collapse. We often find a high degree of muscular development compensating for defective osseous elements. Patients with debilitating diseases such as tuberculosis, in which muscular competence is at a low ebb, frequently have feet with an exceptionally strong osseous pattern. Another type of acceptable foot is the post-poliomyelitic patient whose foot stabilization has been established through triple arthrodesis, thereby compensating for a lack of muscular equilibrium.

Reflection on the objectives of foot practice indicates that we are constantly striving to remove feet from an abnormal status to a normal, or acceptable, one. Unless the foot is abnormal because of muscular instability, it becomes a difficult proposition to offer a prognosis of complete normalcy. If the foot is abnormal because of structural osseous defect, a prognosis of an acceptable foot is all that can be offered. In the case of abnormalcy through osseous defect, an acceptable foot may be attained by creating a high degree of muscular compensation or, on the other hand, by using an orthopedic appliance to compensate for the structural defect.

In this discussion of the general competence of the foot, standards are offered as a starting point in clinical investigation.

ESTABLISHING THE NATURE OF STRUCTURAL STABILITY OF THE FOOT IN STANCE

The foregoing discussion of the competence of the human foot is based on the osseous system of the foot, the ligaments which provide an integument, and the muscles which keep it in a state of equilibrium. During a portion of man's daily existence, the foot participates in the fundamental function of supporting the body weight while the person is standing still. At such times the feet are functioning as architectural bases and muscular effort is at a minimum.

The form of the foot is the result of an integrated arrangement of the foot bones designed to deploy the body weight to maximum advantage against gravity. It is convenient to describe the arrangement in terms of bony arches: the medial, longitudinal arch describes from the calcaneus through the talus, the navicular, the cuneiforms, and the first three metatarsals; the lateral longitudinal arch describes from the calcaneus through the cuboid bone and the fourth and fifth metatarsals; and a transverse arch follows the dome of the tarsal bones across the cuneiform to the cuboid. At the distal extremity of the longitudinal arches the toes lie straight and the metatarsal heads are on a contact plane when weight is borne. No arch formation is present at this level A line drawn through all metatarso-phalangeal joints makes a parabola. A line drawn through the mid-tarsal joint is a cyma.

and examination of thousands of individuals were made, a definite percentage of normal feet could be expected. In a very limited survey consisting of a study of 51 senior college students, 38 presented normal feet, 10 presented abnormal feet, and three presented acceptable feet. This survey included a radiographic analysis as well as a brief clinical examination.

Abnormal Foot

An abnormal foot fails to maintain integrity through muscular imbalance, or an osseous pattern lacking stability, or a combination of both faults.

A simple explanation of this definition would describe an abnormal foot as a weak foot, either because the muscular system is unstable, or because the foot structure is composed of misshapen bones or a mal-aligned bony arrangement, or possibly because both of these deficiencies are present.

It is easy to cite examples of muscular incompetence contributing to foot weakness. Perhaps the most common one is contracture of the calf muscle group which limits extension of the foot and promotes metatarsal problems and a plantigrade position of the calcaneus. Of course, the various forms of paralysis create special deformities. The lack of normal power of the peroneus longus predisposes a foot to planus, whereas a spasm of the peroneus brevis promotes an abducted forefoot posture.

Defects of the osseous pattern are numerous. Atavistic bone shapes, such as the os tibiale externum and the short first metatarsal bone, contribute to some primary weaknesses. Atavistic bone shapes are also largely responsible for hallux valgus problems. Acquired alterations of bony alignment of the foot structure place the foot at a mechanical disadvantage so that it cannot enjoy proper function.

Instances of a combination of fault factors are constantly found, since a major fault in either category will eventually involve both systems. An inherited foot pattern of instability will exert great demands on the muscular system, to the ultimate disadvantage of the foot as these excesses are developed. The result is an involvement of both systems.

A leg structure composed of weak muscular elements in combination with a weak osseous pattern is a rather common problem in the practice of foot orthopedics.

Acceptable Foot

An acceptable foot maintains integrity within limitations. Deficiencies of muscular equilibrium may be compensated for by an exceptionally strong osseous pattern, or there may be a defective osseous structure compensated for by muscular adaptation.

Acceptable feet perform the demands of the individual in the needs of daily life. They must be evaluated on a strictly individual basis. Often, although the foot is acceptable, it is apparent that it is disposed to give trouble. Preventive measures should be taken in anticipation of this. In day-by-day foot practice, one sees demonstrations of this definition when it is the office procedure to do a survey examination of every case presented.

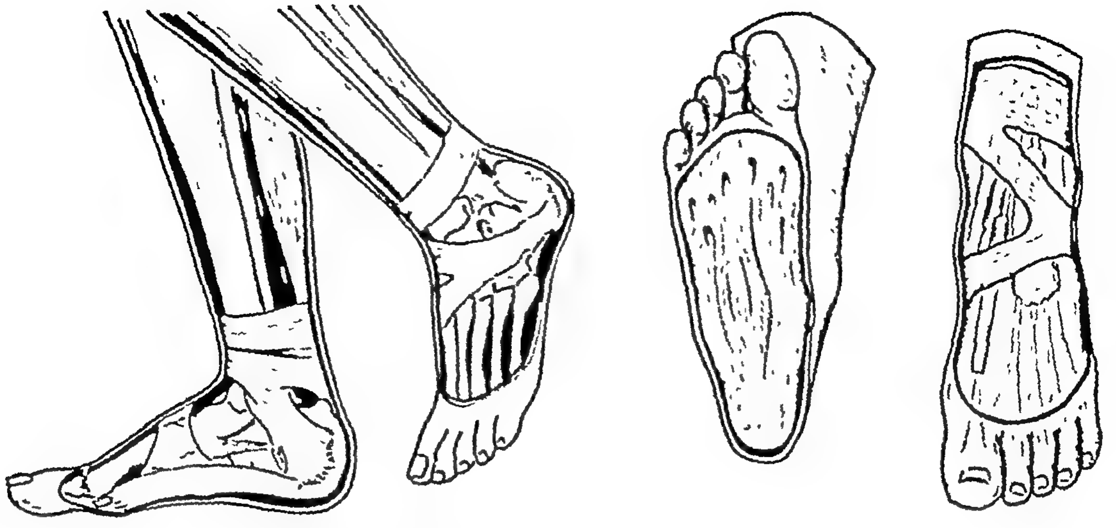

FIG. 5. Superficial Binding Ligaments.

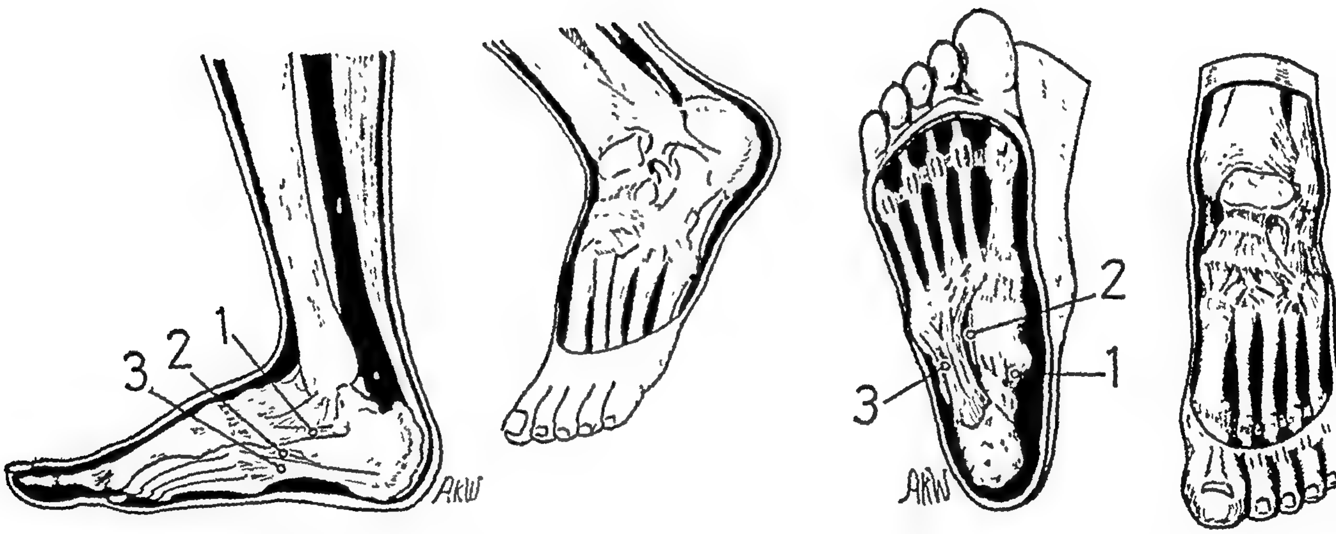

FIG. 6. Deep Ligament System. Ligaments severed in previous experiment: (1) Inferior calcaneo-navicular ligament. (2) Short calcaneo-cuboid ligament. (3) Long calcaneo-cuboid ligament.

Figs. 5–6. Ligaments Maintain Foot Form

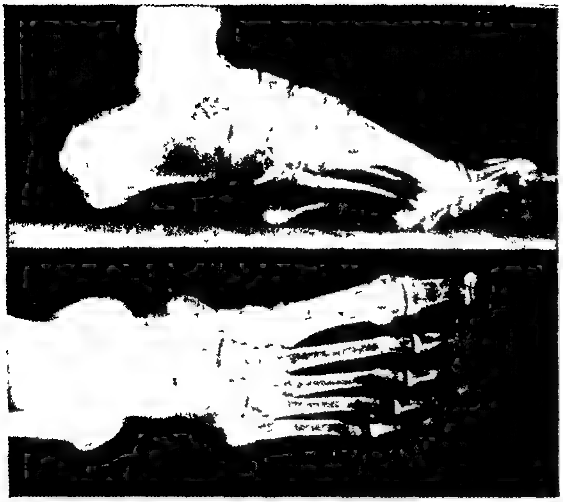

FIG. 1. Dissected Foot Under 50 Kg. Pressure. Muscles removed. Ligaments intact. Structural integrity maintained.

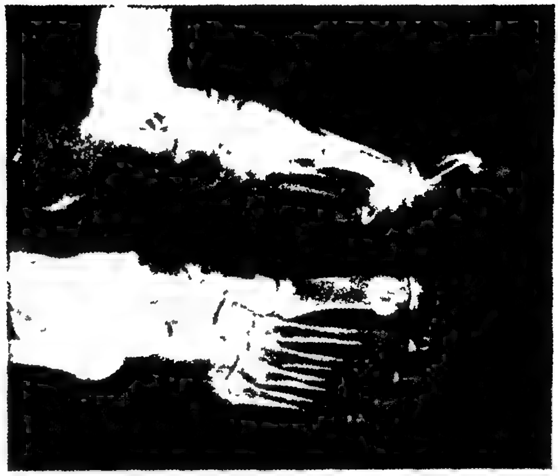

FIG 2 Inferior Calcaneo-navicular Ligament Severed. Minimal (7 mm) elongation of foot.

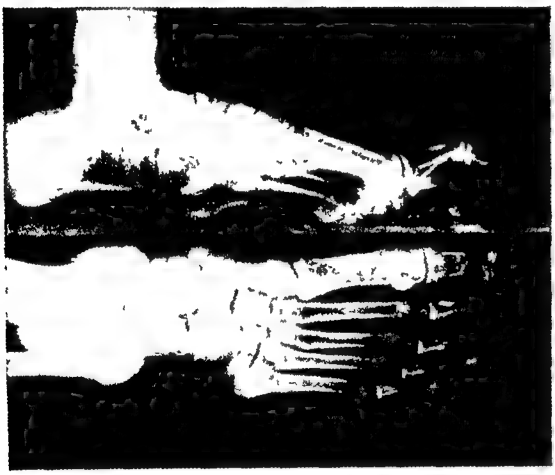

FIG. 3. Short Calcaneo-cuboid Ligament Severed at Calcaneo-cuboid Joint. Slight spreading of calcaneo-cuboid joint

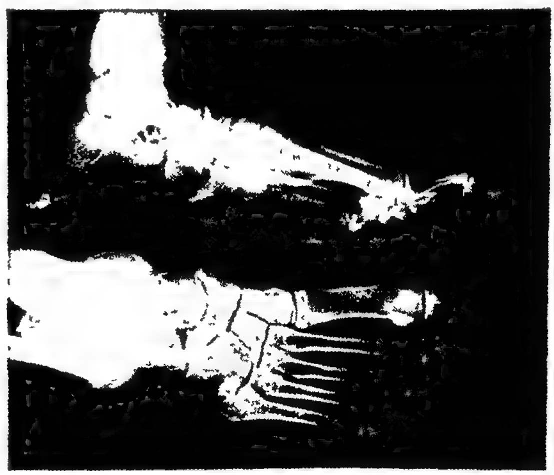

FIG 4 Long Calcaneo-cuboid Ligament Severed *in Toto*. Slight eversion and increased elongation

Figs. 1–4. Radiographs of Anatomy Laboratory Experiment to Demonstrate Structural Stability of the Foot

severing of the specific ligaments. The radiograph of the dissected foot with ligaments severed did not closely resemble radiographs of a foot mal-aligned through natural causes. From this we concluded that the collapse of a foot structure is the result of an insidious elongation of every foot ligament. It is the all-inclusive degeneration of ligament integrity that causes the complete loss of foot form rather than the weakness of a few specific ligaments that bind together important joints of the foot. In our dissected foot, there were no essential changes in the cuneiform bones; the toes did not become deflected; the metatarsal bones assumed no varus slant; and the talus did not slide forward to such an extent as to obscure the sinus tarsi. The non-elastic ligaments that were not severed continued to preserve these joints and high-lighted the importance of their guardianship of foot integrity.

The evidence seems to indicate clearly that the foot in stance is obligated to maintain a fixed position by virtue of the ligamentous binding, as long as the ligaments retain virility and the foot is of normal alignment (Figs. 5, 6). When foot collapse is imminent, ligaments cannot indefinitely check the retrogression.

It might be erroneously inferred that the rigidity of the foot in stance implies that it is inflexibly locked together by ligaments. Nothing could be farther from the truth. Ligaments are arranged in such a manner that all normal foot motions may be executed with complete flexibility. Motion of the foot at the ankle joint is a striking example of the extreme range of motion in a sagittal plane and the complete stability, of an unyielding character, in the frontal plane (Fig. 7).

Mennell explains the relationship of ligaments to joint excursion in this manner: "The function of these ligamentous fibers can only be, as in all joints, to act as buffers to counteract the inimical forces of external strain and stress, and to put a check on movements when the physiological limit has been reached." It is our contention that the foot in stance exemplifies an arrested phase of joint excursion.

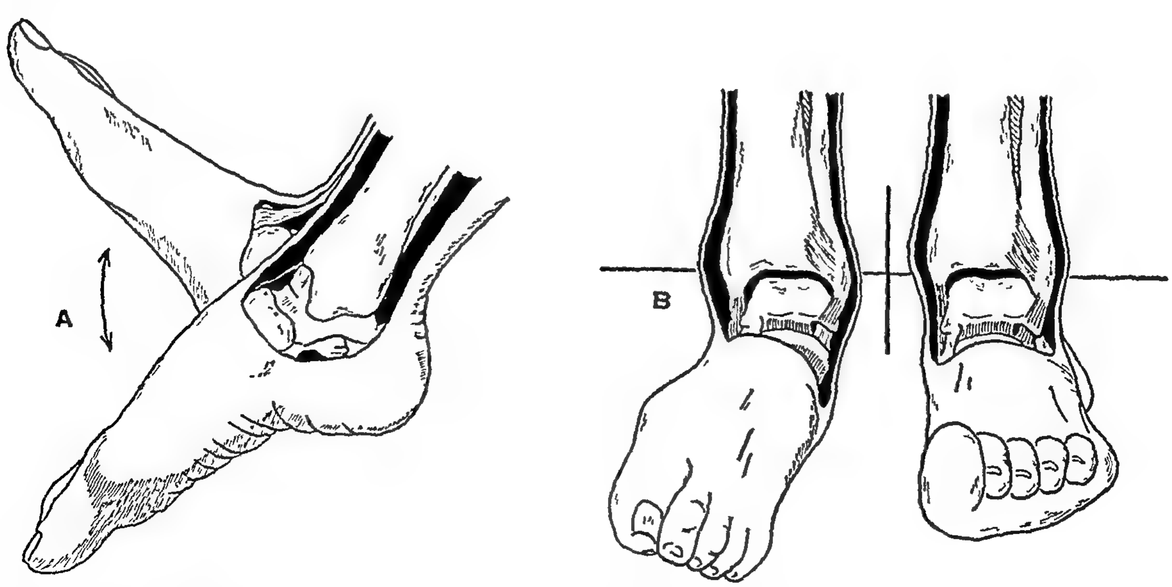

FIG 7. LIGAMENTS CONTROL JOINT MOTION. (A) Free motion of ankle joint in sagittal plane. (B) Stabilized ankle joint in frontal plane.

Lake took the initiative in stressing the structural integrity of the foot by performing a unique experiment. He used the extremity of a cadaver and removed all muscular attachments arising in the leg, after which he exerted weight through the foot. The form of the foot did not alter. From this it was concluded that the shapes and arrangements of the bones could be maintained by the ligamentous integument solely. This view has been substantiated and endorsed by other investigators Lapidus sought to correct the misconception that the longitudinal arch had the qualities of a semi-elliptic spring by applying the *Biochemical Studies of Fibrous Tissues Applied to Fascial Surgery*, by Gratz, to the plantar fascia. Gratz claims that the elongation of the ligamentous type of tissue is less than 2 per cent, with a tensile load of 100 kg. per cm. of cross-section. These experiments were made under carefully controlled conditions. According to Lapidus, a plantar fascia 15 cm. long and 5 cm. in cross-section, carrying the 60 kg. load of a man standing on one foot, would elongate 0.21 cm. This in turn would allow for sagging of the apex of the longitudinal arch (at the head of the talus) amounting to 0.1 cm., thereby indicating the relative non-elasticity of the structure. He suggests that the arch does not decrease in an anesthetized person, nor does paralysis cause flattening of the long arch He also points out that normal standing, if prolonged, would be exhausting through muscle fatigue if it were dependent on muscular support Dunn came to the same conclusion in his thesis, *The Statics of the Human Arch When Subjected to Body-Weight.* He states, "The reaction of an arch to static forces depends almost entirely upon the integrity of the ligaments by which it is supported."

Harford and this writer elaborated on Lake's experiments on two occasions in an effort to obtain an indication where ligaments were most responsible for maintaining the integrity of the form of the foot Results of the experiments were similar in both instances. The specimen selected simulated good foot form of medium arch height and was severed from the cadaver at the knee. All tissues were dissected from the leg and foot except the ligamentous integument and a few inconsequential interosseous muscles which help prevent excessive spreading of the metatarsal bones Lateral and dorso-plantar radiographs of the experiment were recorded for purposes of analysis The first radiographs were made with Harford directing the weight of approximately 50 kg through the leg bones to the foot (Fig 1). No change in form was noted Next, the inferior calcaneo-navicular ligament was severed and a slight elongation of the foot was noted (Fig 2). Radiographs confirmed a slight lowering of the pitch of the calcaneus and a forward, downward, and medial displacement of the talus A gain of 7 mm in arch length was measured. Next, the short plantar ligament was severed at the junction of the calcaneo-cuboid joint (Fig 3) The longitudinal arches became further depressed and increased joint space was visualized radiographically at the calcaneo-cuboid joint Finally, the long plantar ligament was severed *in toto* (Fig 4) The foot then assumed a more pronated attitude with a more plantigrade position and a greater medial rotation of the talus Radiographs confirmed these changes.

The experiment just described produced some interesting findings. The changes occurring in the foot were limited precisely to the areas involved in the

severing of the specific ligaments. The radiograph of the dissected foot with ligaments severed did not closely resemble radiographs of a foot mal-aligned through natural causes. From this we concluded that the collapse of a foot structure is the result of an insidious elongation of every foot ligament. It is the all-inclusive degeneration of ligament integrity that causes the complete loss of foot form rather than the weakness of a few specific ligaments that bind together important joints of the foot. In our dissected foot, there were no essential changes in the cuneiform bones; the toes did not become deflected; the metatarsal bones assumed no varus slant; and the talus did not slide forward to such an extent as to obscure the sinus tarsi. The non-elastic ligaments that were not severed continued to preserve these joints and high-lighted the importance of their guardianship of foot integrity.

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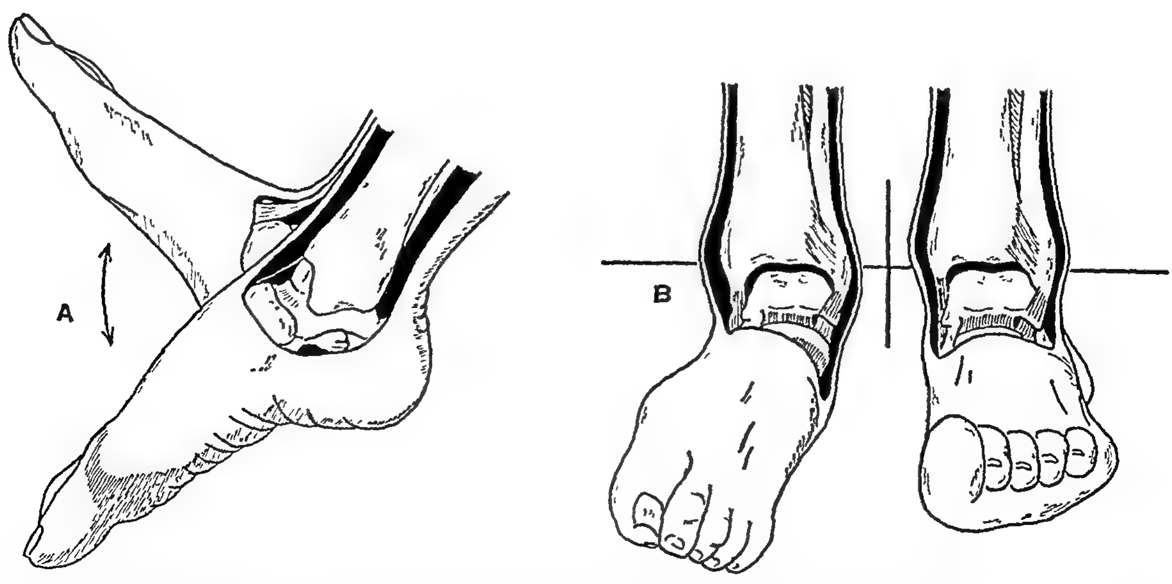

FIG. 7. LIGAMENTS CONTROL JOINT MOTION. (A) Free motion of ankle joint in sagittal plane. (B) Stabilized ankle joint in frontal plane.

The ligament structures, although non-elastic from the standpoint of direct stretch, are arranged in order to permit an excursion of the joint. Slack is provided where needed. The great strength of ligament tissue may be realized when we consider the common trauma of avulsion of a portion of bone where injuries result in the twisting of a joint beyond its normal limit, instead of tearing or rupturing the ligament. This is a common occurrence.

Perkins makes an interesting point when he says, "The longitudinal arch supports itself so long as the muscles balance the joints of the arch in such a way that stress passes through the center of these joints." This emphasizes the importance of accurate alignment of the foot bones in an osseous pattern of stability. He continues, "When weight does not pass directly through the center of the joint, the ligaments are subjected to tension." It is this unremitting tension that provokes foot collapse with all of the kindred mal-alignments.

Steindler presents the verdict concisely when he says: "The integrity of the form of the foot is entrusted first to its ligaments and secondly to its muscular apparatus."

Foot Equilibrium. Stabilization of the form of the foot pre-supposes a well-balanced body, from the standpoint of general body mechanics. Due to the force of gravity, the stress of body weight reaches the foot through the center of the talus. Pressure stresses are transmitted to the forefoot and hindfoot. Counter-resistance is created by the areas and points of foot contact. The sum of the pressure stresses and the counter-resistance must be equal.

A reasonable state of balance strength is present in the muscles which move the foot on the leg and in those muscles which create foot and toe motions. This is commonly referred to as equilibrium. The equilibrium of the static foot and that of the dynamic foot is very different. As we have discussed in the previous section, ligaments maintain the integrity of foot form when a person is in a standing position, whereas the muscles stand in the first line of defense during the dynamic use of the foot When the ligaments of the foot have weakened, the muscles are required to maintain foot stability during the act of standing (Figs 8–13)

Willis emphasized that the function of the long leg muscles coursing to the plantar aspect of the foot is the support of the longitudinal arch, while Jones through experimental studies of static forces claims that not more than 15 to 20 per cent of the total tension of the longitudinal arch is borne by the posterior tibial and peroneal muscles. Much the greater part of the tension stress of the longitudinal arch is borne by the plantar ligaments of the foot, and the short plantar muscles also contribute to the support of the arch, according to Jones's experiments He claims that by reason of their position and relationships they are better adapted to support the longitudinal arch than the long muscles

Muscle Dynamics. The actions of the various muscles of the leg that move the foot upon the leg and those muscles which create foot and toe motions provide a very extensive field of study. The dynamic action of the muscles provides power and control during foot motion. The action of one muscle group is counter-balanced by the opposing action of another Equilibrium of muscle action is controlled through the synergistic action of muscle interplay and the ex-

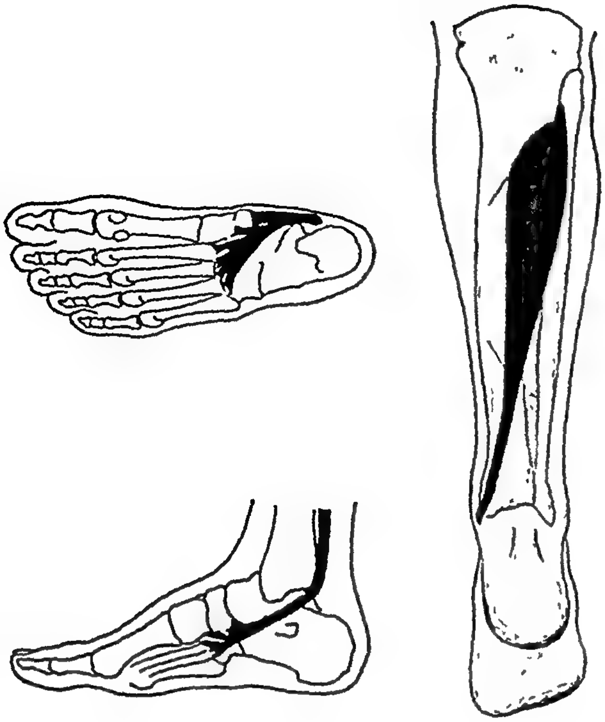

Fig. 8. Tibialis Posterior. Inserts plantar-wise to the navicular, cuneiforms, cuboid and sustentaculum tali. Follows a supportive course behind the medial malleolus to the posterior and lateral part of the leg, deep in the upper third Stabilizes the long arch by an adduction pull on the foot.

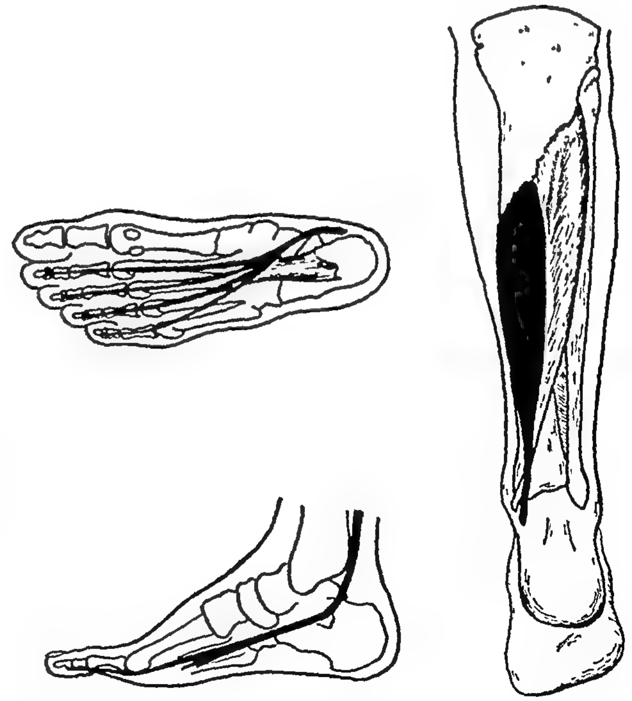

Fig. 9. Flexor Digitorum Longus. Inserts into the distal phalanges of the toes Gains leverage by a course behind the medial malleolus to the middle third of the leg. Checks foot elongation by flexing action

Figs. 8–13. Muscles Stabilize Foot Form

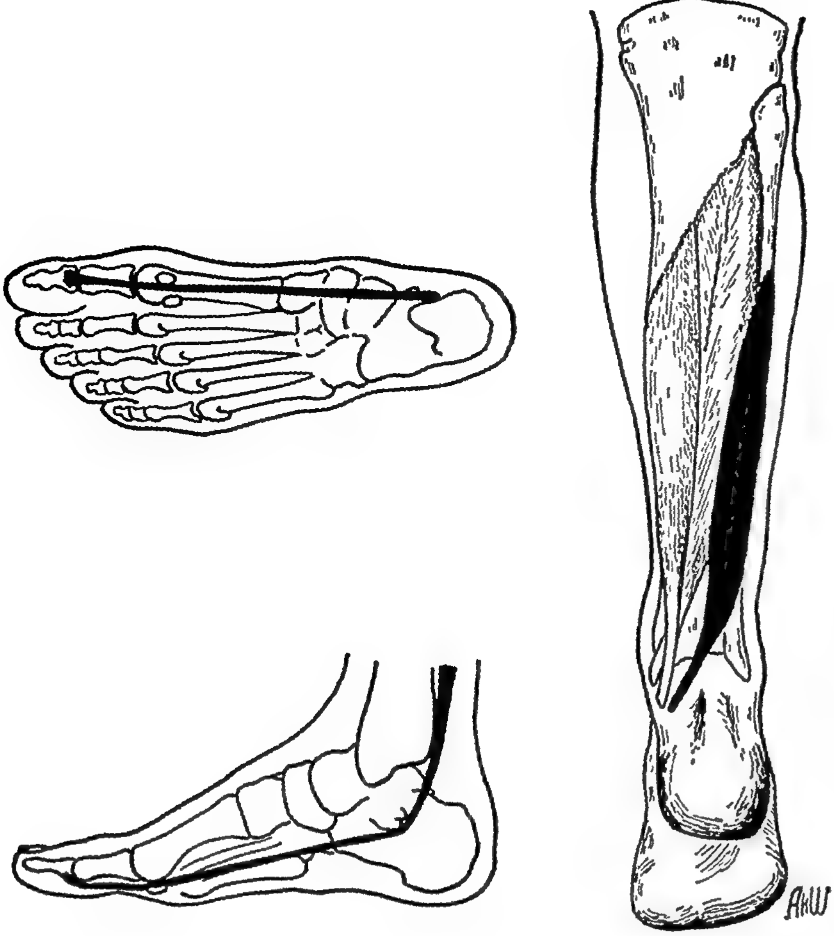

FIG 10. FLEXOR HALLUCIS LONGUS. Inserts into the base of the distal phalanx of the great toe. Follows a course under the sustentaculum tali in back of the ankle to the lower two-thirds of the fibula, and exerts a powerful flexing action to the great toe and extension of the foot.

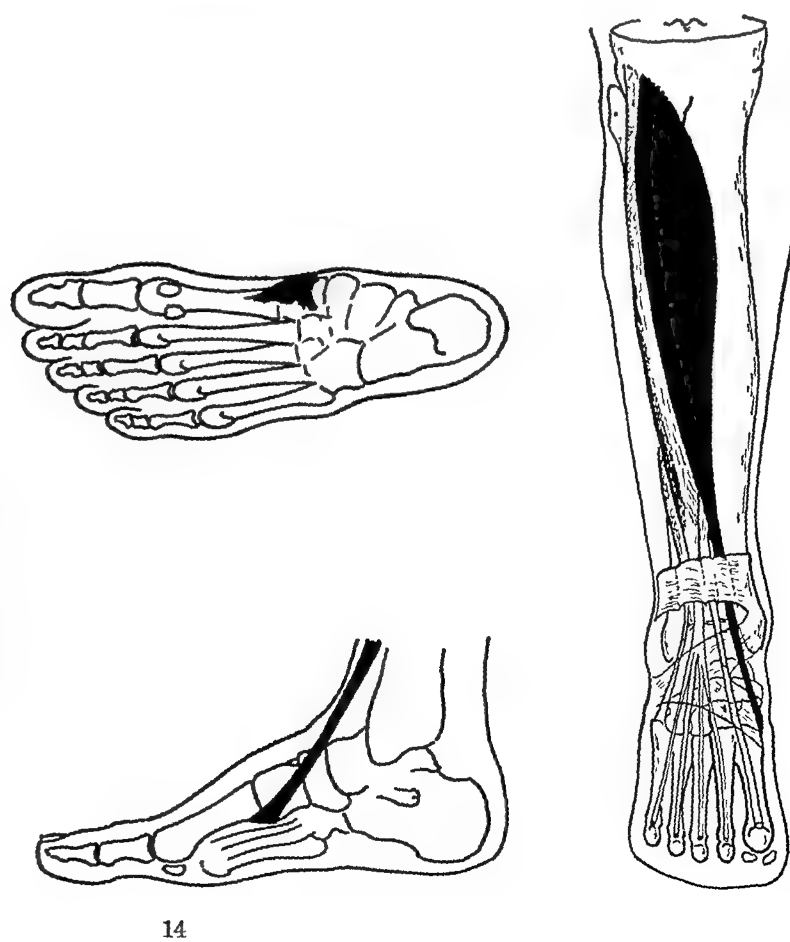

FIG. 11. TIBIALIS ANTERIOR. Inserts into the medial and plantar surfaces of the internal cuneiform and first metatarsal. Follows a direct course along the dorsum of the foot and up obliquely to the upper third of the leg. Exerts a direct pull on the medial arch by its action, inverting the foot.

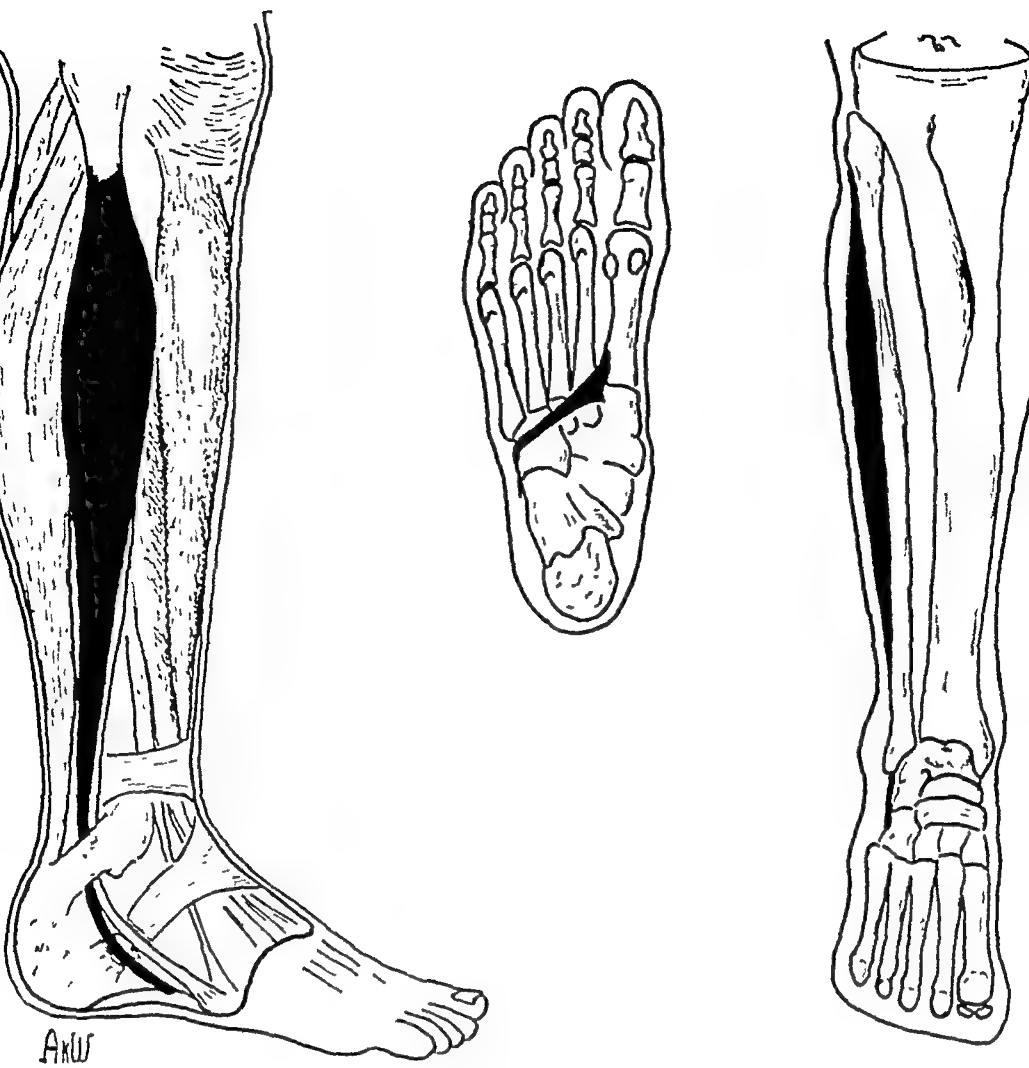

Fig. 12 Peroneus Longus. Inserts at the lateral side of the medial cuneiform and the base of the first metatarsal plantarly. Takes a tie-band course across the transverse arch of the foot under the cuboid bone, in back of the lateral malleolus and up the leg to the upper two-thirds. Holds the transverse arch together. Its action in holding the sub-metatarsal prominence in firm contact through extension of the foot helps preserve the medial longitudinal arch.

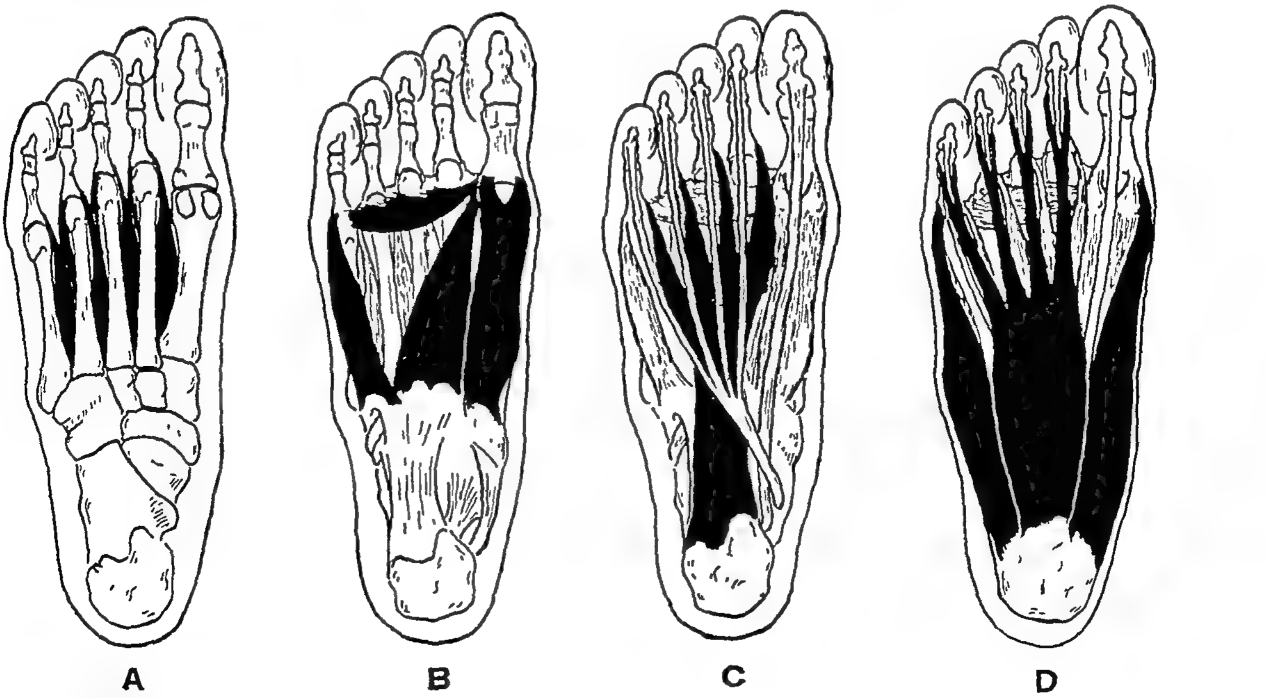

Fig 13 Intrinsic Foot Muscles. (a) *Interossei* Stabilize toe alignment. (b) *Flexor Hallucis Brevis.* Strengthens medial arch segment. *Flexor Digiti Quinti Brevis.* Strengthens lateral arch segment. *Adductor Hallucis* Checks hypermobility of metatarsal segment *Adductor Transversus.* Checks spread of metatarsals. (c) *Lumbricales* Prevent toe deviation *Quadratus Plantae* Assists in toe flexion and prevents deviation of toes (d) *Flexor Digitorum Brevis.* Prevents foot elongation by toe flexion. *Abductor Digiti Quinti.* Lateral arch stabilizer *Abductor Hallucis* Medial arch stabilizer

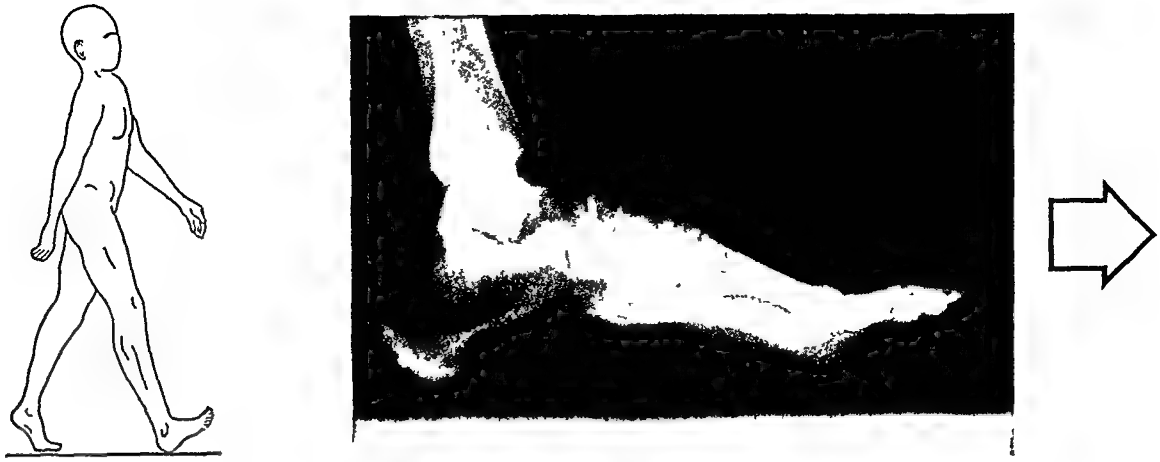

Fig 14. Weight Forces Received Through Heel.

Fig. 16. Maximum Stress on One Foot.

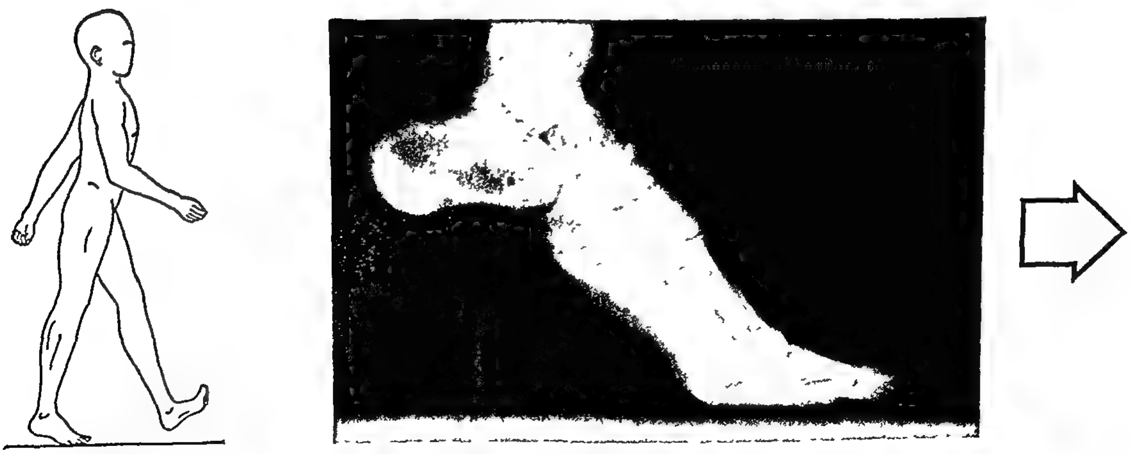

Fig. 18. All Weight Force on Metatarso-phalangeal Joints and Toes

Figs. 14–19. Radiographic Study of Phases of the Walking Gait

Fig. 15. Transmitting Weight Forces to Forefoot.

Fig. 17. Raising Weight Force at Start of Take-off.

Fig 19. Foot Free While Carried Forward for Next Step.

tended use of a muscle to complement its primary purpose. The force of gravity and the responding posture of the foot are used to maximum advantage in establishing equilibrium.

When an intimate knowledge of the action of each motion is discerned, it may be applied to the analysis of radiographs of the disordered foot so that we may visualize the altered anatomy that would occur as a result of muscle imbalance. It is also important to analyze phases of the walking gait in terms of muscle dynamics, and the way they are related to radiographs of the foot structure (Figs. 14–19). The same type of analysis should be applied to other group efforts of muscle action, such as muscles that adjust the foot to uneven surfaces, muscles that stabilize the foot against lateral and medial imbalance, muscles that produce collective purchase power in the toes, muscles that hold the toes in straight alignment, muscles that produce strong purchase power while the body weight is raised, muscles which initiate gait by raising the body, and muscles that produce individual toe action for the deployment of the foot in a variety of situations.

The power and strength of the muscles and their ability to preserve foot equilibrium may be dramatically tested by having a person stand on one foot for 1 minute. A rippling interplay of the muscular effort may be seen and felt in the leg and tendons passing to the foot. The complete maintenance of normal form and conformation in a strong foot is striking whereas the instability and loss of integrity and foot form in the weak foot is indisputable

The Foot Mechanism Emphasized. This entire chapter has been devoted to emphasizing the intricate nature of foot structure and mechanics. The mobility of the foot and its delicately balanced functions have been elucidated so that the reader may orient the material that will follow concerning radiographic interpretations in a more applied manner than could be obtained by a strictly objective presentation of the roentgen appearances. Without this discussion, one might place the viewpoint of this book in the category of the strict morphological theorists It is our contention that it is impossible to separate the importance of foot morphology from foot function

Features of foot mechanism will be presented in succeeding chapters and will be treated as the occasion requires. Since it is an objective method of recording, radiography can only portray anatomy and patho-anatomy Knowledge acquired through research, experimentation, and practice, will add the viewpoint needed to convert patho-anatomy into patho-mechanics.

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Chapter II

Radiographic Visualization of the Normal Foot

A normal foot should possess an osseous pattern of stability. Since it is inconceivable that every foot should possess identical characteristics, this definition allows a latitude of reasonable proportion. Variations in both body-type and racial strain account for the different kinds of feet, such as long, thin feet, short, broad ones, heavy-boned types, and light-boned ones. In spite of this variation, there should exist standards of common normalcy in regard to the shapes of the individual bones and the alignment of their dominant structural patterns. In this way, stability is assured.

The adult foot has been chosen as the subject of study in roentgen visualization because all the bones have matured and a complete continuity of osseous elements is present. In the radiograph of a foot prior to maturity, only the mineralized zones may be visualized.

As we explore radiographic visualizations, emphasis will be placed on features relating to the disordered foot (discussed in later chapters). Additional comment will be made where necessary to clarify descriptions and to correlate anatomical and physiological factors of interest. Unless otherwise stated, the word "medial" will refer to midline of the body, and the word "lateral" away from midline of the body.

Our research has been standardized on the basis of radiographs of the foot performed in the standing position. In this attitude, the physical forces exert a stress effect on the foot and all the structural strength or weakness is apparent. As in all radiographic representations, the shape and appearance of the bones are determined by the radiographic view portrayed. Our standardization will consist of the lateral and dorso-plantar views Superimposition of bones, such as that of the medial longitudinal arch over the lateral longitudinal arch, can be evaluated in some degree on the basis of experience and by delineating each bone in its proper spatial relationship. Since the medial border of the foot is placed in contact with the film-holder in the lateral exposure technique, the radiographic representation defines the elements of the medial longitudinal arch most accurately. Summations of density provide a clue to certain anatomical landmarks such as the sustentaculum tali as visualized from the lateral view, and the contours of bones such as the plantar tuberosities of the calcaneus.

These details should be a routine consideration of every radiograph. The student should refer to a specimen foot skeleton to master the full form produced by blending two radiographic views to make a third-dimensional view.

The criteria we offer are given in detail so that the investigator may have a complete understanding of the normal structural status of the foot. The summary and illustrations will serve as practical guides for ready reference.

An appraisal of normalcy from a radiographic viewpoint is concerned with a conformity of characteristic patterns created by the alignment of the bony elements of the foot, individual bone shapes, and the articular composition of the foot bones.

CHARACTERISTIC STRUCTURAL PATTERNS OF THE FOOT

Arch Conformations. The lateral radiographic view demonstrates a configuration of longitudinal arches. The medial longitudinal arch is visualized by continuity from the plantar tuberosity of the calcaneus to the talus, to the navicular, to the medial cuneiform bone, to the first metatarsal, and finally to the base (consisting of the sesamoids and the metatarso-phalangeal joint). The lateral longitudinal arch is visualized by the plantar continuity of the calcaneus which represents one base of the arch, and the head of the fifth metatarsal which represents the other base, plus the cuboid which represents the keystone. Plantar fascia secure the bases of the arch structure

The morphology of the arch takes on significance when it is related to the stresses it is designed to sustain. Meldman describes the inter-relationship of the two arches as a decussation of weight transmission in both a forward and a lateral direction from which the various phases of the locomotor cycle are evolved. In the anterior lateral quadrant of the foot, the connecting link joins the two segments at the lateral cuneiform-cuboid joint and the third metatarsal-fourth metatarsal base. In the posterior area of the foot, the sustentaculum tali and the posterior subtalor articulation receive a more direct weight transmission from the talus.

Methods of Mensuration. In the past, much attention was paid to the height of the medial longitudinal arch as the criterion for determining a useful and normal foot We accept the fact that the arches are absolutely essential in describing the continuity of foot bone alignment, but we refuse to consider the height of the medial longitudinal arch of prime importance in evaluating normalcy of the foot Kaplan and Symonds devised an ingenious method of mensuration in which the head and base of the first metatarsal, and the plantar tuberosity of the calcaneus were used as the three points in a system to determine the height of the longitudinal arch. Moreau and Bertani use the following points in measurement of the longitudinal arch: the lowest point of the calcaneus where it touches a horizontal plane, the lowest point of the head of the talus, and the lowest point of the first metatarsal where it touches the horizontal plane Again a set of values, prepared by an angulation assessment, is offered as a guide to normal arch height and flat-foot condition

In a paper published in 1937, *The X-Ray Analysis of Weak Foot,* this writer presented a chart of measurements as a guide of normalcy The angle of devia-

tion of the calcaneus from the weight-bearing plane was given as 30° and the height of the cuboid above the weight-bearing plane was given as 10 mm. These figures were not arbitrary. They were "average" values obtained by computing the mathematical mean of numerous cases. This is a common anthropometric practice that clings to morphology *per se*, rather than a concept of physiological determination. Harris and Beath, in their comprehensive "Canadian Army Foot Survey," have applied statistical computation and analysis to over 20 features of the foot structure (many of them paralleling our early work) with the frequent conclusion that the results are of anthropomorphic value and not to be used in evaluating the individual case. Other phases of their survey are most extraordinary in providing statistical data of inestimable value in correlating clinical problems. Rampsberger makes the following pertinent statement which points up the value of such a survey: "Objects are related in many different ways and mathematical science does not have a monopoly on true knowledge."

One critical deficiency of measurements is the manner in which the base lines are sometimes established as a starting point in charting. This was recognized when a line selected as the axis of balance was related to the conventional dorso-plantar radiograph. In such cases the line had to be drawn from a point between the second and third metatarsal heads to a point at the center of the calcaneus. From the conventional dorso-plantar radiograph it is impossible to determine accurately the center of the calcaneus, because the superimposed images of the leg structures extend to infinity at the posterior aspect. This particular problem was overcome by developing the full-foot technique, in which the posterior aspect of the calcaneus is superimposed on the conventional forefoot radiograph, thereby permitting accurate location of the axis of balance.

Figs. 20–22. Arch Height Varies in Normal Feet with Pitch of Calcaneus

Fig 20. Normal Low Arch: 10–20°

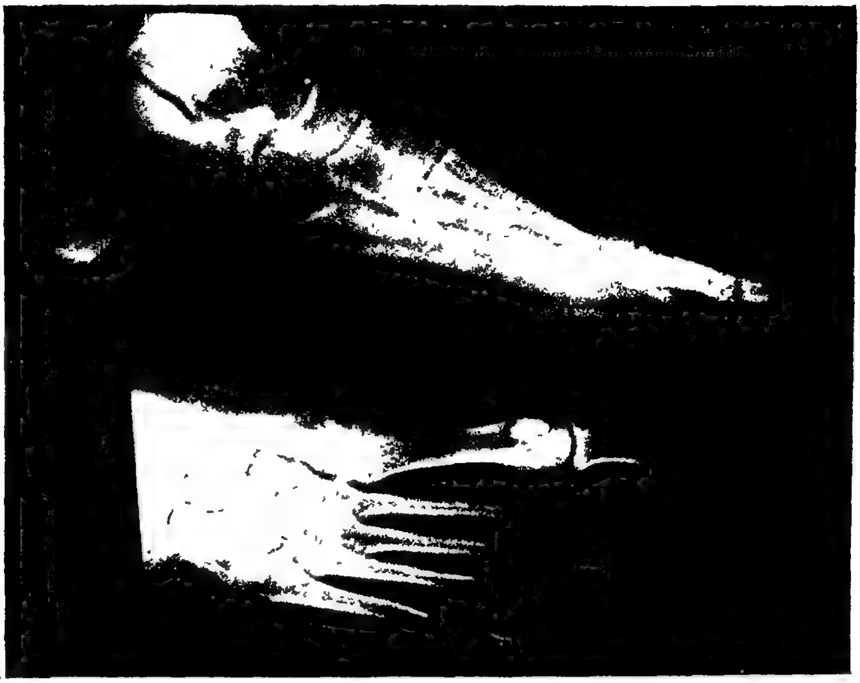


Fig. 21. Normal Medium Arch 20–30°

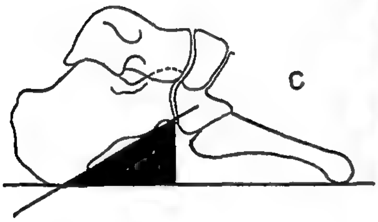
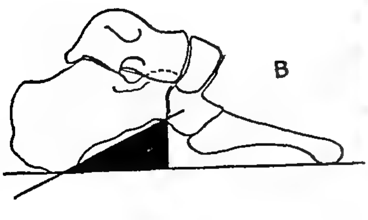


Fig 22 Normal High Arch 30–45°.



Another instance of deficiency is the measurement that relates the position of the sesamoid bones to the distal end of the first metatarsal bone. Despite accurate measurement, these bones may be greatly diverted in relative position, unless implicit standardization of radiographic technique is followed. Some investigators accept arbitrary base lines that are influenced both by variation in bone shapes and other intrinsic alterations that invalidate their authenticity.

The crux of an evaluation of measurements is that they must mean something. To be effective they must be applied to the individual case, and all the various measurements pertaining to the case must be considered in relation to one another, within the structure of the case. When this is done, the danger of unrelated statistical conclusions is reduced to a minimum.

We prefer to reduce the actual measurement features to a minimum in appraising the characteristics of a normal foot. At the risk of seeming arbitrary, estimates of mal-alignment and altered shapes will be given to aid in judging the radiograph. Actually, extensive statistical computations have been used to arrive at the estimates given.

Arch Height (Figs 20–22). It is our contention that the height of the arch is of little consequence in the evaluation of a normal configuration of the foot in relation to the functional alignment and integrity of its bony elements. The height of the arch is chiefly determined by pitch and shape of the calcaneus, since foot alignment stems from articulations with the calcaneus. The angle presented by the inferior surface of the calcaneus in relation to the weight-supporting plane may vary from 10° to 45° in the normal foot, provided that the foot qualifies in respect to normal bone shape and alignments throughout.

For practical purposes, the 30° arch height, previously considered average, may be classified as the medium height, rather than the normal height. The height of the low-arch type of foot ranges down to 10° and that of the high-arch type up to 45°.

It is the clinical observation of many investigators that the height of the longitudinal arch is of little importance in determining its competence. We concur with this whole-heartedly, with one reservation. As Whitman points out, "even the inherited flat foot or the foot which has never caused symptoms is weak in the sense that, in use, it lacks the symmetry and elasticity characteristic of the perfect machine."

HINDFOOT AND MID-TARSAL JOINT ORGANIZATION

It is practically axiomatic that the form and integrity of the foot are reasonably assured if the bones that enter into the articulation of the mid-tarsal joint are normal in shape and are in proper alignment. A normal mid-tarsal joint indicates that the calcaneus is in a properly aligned position and that the talus is properly seated on the calcaneus. This resolves the strength of the hindfoot.

If the mid-tarsal joint is normal, the navicular and cuboid bones are bound to articulate properly, since they translate the directional forces of weight transmission from the body into the forefoot and likewise transmit the reactions of contact resistance to the hindfoot. A discrepancy in either direction would weaken this joint and break its normal continuity.

Radiographic Impressions

Mid-tarsal Joint Line. A cyma line (an architectural term designating the union of two curved lines) drawn through the mid-tarsal joint separates the hindfoot bones—the calcaneus and talus—from the forefoot bones—the navicular and cuboid. This line is so well defined that the famous surgeon Chopart has designated it as the site for amputation of the forefoot. Anatomically, this line has been designated by many anatomists as an entity, calling it the mid-tarsal joint. Radiographically, the mid-tarsal joint is visualized exceptionally well by the lateral view of the foot because it is the object of the focusing effort to direct the central ray through this joint on a parallel plane. Continuity of this important anatomical line is perhaps the most outstanding index of foot normalcy. Radiographically, the head of the talus should be continuous with the anterior joint surface of the calcaneus to establish the normal mid-tarsal joint line. This is true in both lateral and dorso-plantar views (Fig. 23).

Sinus Tarsi. Another key radiographic feature of good alignment of the bones of the mid-tarsal joint is the representation of the sinus tarsi as visualized in the lateral radiograph (Fig. 24). Actually, the sinus tarsi is a combination of two things, the sulcus tali and the sulcus calcanei. These form a canal, originating as a narrow opening posterior to the sustentaculum tali, and following an oblique course forward into an open sinus on the lateral side, anterior to the main body of the talus. It contains the talo-calcaneal ligaments, which powerfully bind the subtalor articulation together.

The decreased density of the sinus accounts for a radiographic appearance (found just anterior and superior to the sustentaculum tali) which is oblong in shape when the talus is properly seated on the calcaneus. The oval area is precisely where the neck of the talus joins the body at its inferior surface. When fully visualized with good alignment, the joint space of the talo-calcaneal articulation will be sharply demarcated about midway within the appearance of the sinus tarsi. This indicates that the subtalor joint is level and the calcaneus is in good position.

Position of the Talus. In spite of its key position, the talus is a passive bone because there are no muscular attachments to it. As long as the integrity of the foot is assured, the talus maintains its proper position. It moves according to

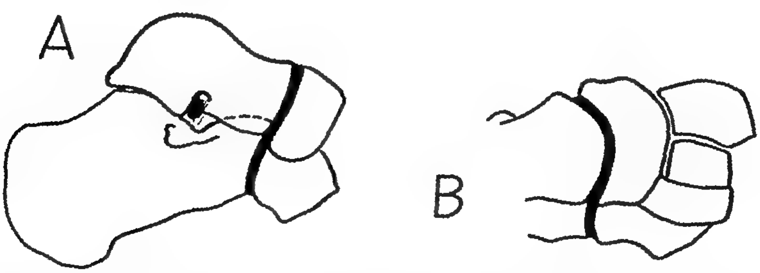


Fig. 23. Mid-tarsal Joint Line a Continuous Cyma in Both (a) Lateral View, and (b) Dorso-plantar View.

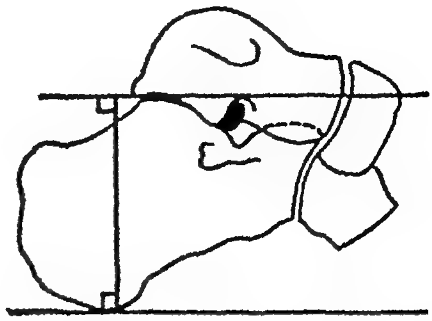


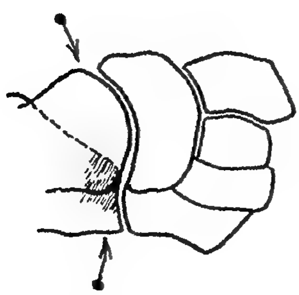
FIG 24. (Left) Visible Sinus Tarsi Indicates Proper Seating of Talus—A Key Feature.
FIG. 25. (Right) Talus Normally Parallel with Weight-supporting Plane.

the design of the articular surfaces and the limitation of the ligaments. Under normal circumstances, the talus rests on the calcaneus with the subtalor joint carrying most of the weight on the posterior articulation. The sustentaculum tali acts as a midway weight-receiving and stabilizing post. The anterior facet of the calcaneus, plus the calcaneo-navicular ligaments, supports the anterior surface of the talus.

The radiographic impression of the talus in the lateral view indicates that it is essentially parallel with the weight-bearing plane. A line drawn from the center of the posterior process to a point at the center of the head of the talus should be used to check the possible parallel relationship (Fig. 25). The lateral aspect of the talus is part of the framework of the important posterior subtalor articulation. This process is visualized on the radiograph, midway on the bone, as a triangular-shaped area of density directed plantar-wise. The apex is frequently superimposed over the sustentaculum tali, although actually this process is situated in the wide lateral area of the sinus tarsi.

The posterior process of the talus is in reality part of the roof of the posterior subtalor articulation. It is visualized radiographically as a projection of the extreme posterior margin. It should be borne in mind that this is an integral part of an important articulation, not merely a projection.

The position of the talus as observed in the dorso-plantar view should be related to the calcaneus and the base line indicating the long axis of the foot. This orientation will serve as a double check.



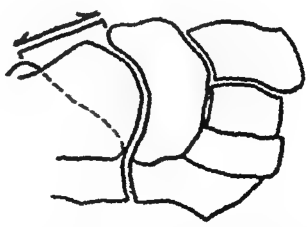


FIG 26. (Left) Talus Normally Bound Closely to Anterior Process of Calcaneus
FIG. 27. (Right) Estimated Length of Inferior Calcaneo-navicular Ligament.

In a normal position, the head of the talus is closely bound to the anterior process of the calcaneus (Fig. 26). This is visualized by the head being superimposed over a portion of the anterior process. The strength of this position is accentuated by the support of the sustentaculum tali, which may be observed as a summation of density when sufficient penetration has been allowed in this view. In this radiographic appearance, the length of the spring ligament may be appraised by the distance from the sustentaculum tali to the navicular (Fig. 27).

The talus is placed in a somewhat eccentric position on the calcaneus in that it rests in part on the sustentaculum tali. Due to the medial inclination of the neck of the talus, it seems to be obliquely positioned in reference to the calcaneus The posterior facet of the subtalor articulations is almost centrally located in reference to the calcaneus, and the body of the talus is practically parallel with the long axis of the foot. Radiographically, the body of the talus is lost in the images of the superimposed leg structures; consequently, its position must be evaluated from the neck and the head of the bone.

The line that we have chosen for the long axis of the foot runs from the center of the posterior aspect of the calcaneus to a point midway between the second and third metatarsal heads. This line is relatively undisturbed by anatomical variations and mal-alignments of the foot, such as would be the case in Feiss's line, which follows the medial border of the foot and could be influenced by hallux valgus.

The establishment of centering points for this line gave rise to considerable study. Since the conventional dorso-plantar radiograph does not demonstrate the heel area, it would be impossible to indicate accurately a centering point, except by guess The full-foot radiographic technique, in which the heel area is superimposed on a conventional dorso-plantar view, was developed to solve this problem. From this composite radiograph it is simple to indicate the long axis line

In order to draw a line through the long axis of the neck of the talus, a point is marked at each of the extreme ends of the rounded head of the talus and a line drawn across. This line is then bisected and a line drawn perpendicular to it This line is extended to the long axis of the foot. The angle formed by these two lines represents the medial inclination of the head of the talus, which should be 15° under average circumstances. This angle seems to be the most significant measurement in appraising normal alignment of the talus to the calcaneus (Fig. 28).

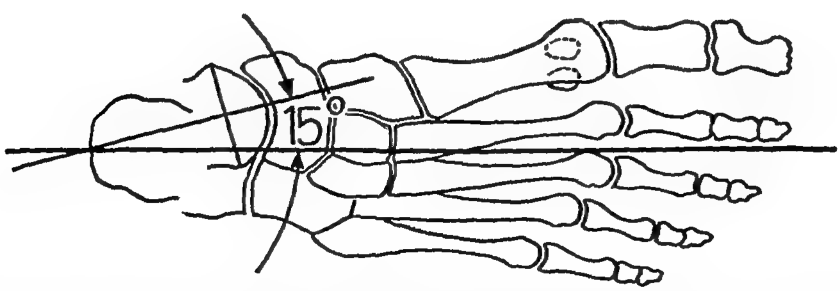


FIG 28 Long Axis of Talus Neck Normally Inclined 15° from the Long Axis of the Foot.

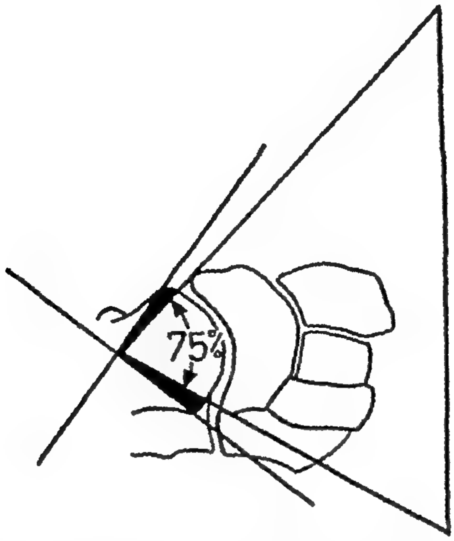


FIG. 29. At Least 75 Per Cent of Head Normally Articulates with Navicular.

Relating the Talus to the Navicular. The most practical assessment of normal alignment may be gained by considering the articulation of the head of the talus with the articular surface of the navicular as viewed in the dorso-plantar view. In normal instances, at least 75 per cent of the talor head should articulate (Fig. 29).

Consideration of the Calcaneus. The position of the calcaneus is of prime importance in the maintenance of normal foot alignment. In addition to being the site of innumerable ligamentous attachments and of the plantar fascia, the calcaneus is the anchoring point of the principal intrinsic muscles of the foot. The prime movers of the body, the triceps surae, terminate in the tendo achilles, which attaches to the posterior aspect of the calcaneus. When all these elements are in proper balance, position, and strength, the calcaneus will be maintained in correct position and foot integrity assured. Baumgaertner and Diamond claim, "as the heel goes so goes the foot." The complete dependence of the talus on calcaneal support is added evidence of the need for proper position.

The radiograph affords only limited visualization of calcaneal position. Nevertheless, all its aspects will be discussed, even though only a few of the radiographic features are clear indications of position.

The angle presented by the inferior surface of the calcaneus and the weight-bearing plane represents the pitch of the calcaneus. The pitch of the calcaneus is visualized in the lateral view and is indicative of arch height. When the pitch has not been altered due to malposition, the talus enjoys a normal status; conversely, we may evaluate an abnormal pitch by the changes that take place in the mid-tarsal joint. In a comparative study of both feet of an individual, the pitch of the calcaneus is usually uniform; hence, a variation in pitch would serve to indicate which foot is more nearly normal

The posterior subtalor joint surface of the calcaneus lies on a relatively level plane in reference to the standing surface. This is evident in the lateral view of the posterior portion of the articulation. The anterior process of the calcaneus is variable in shape and size and is unreliable as a guide in evaluating the position

In a normal position, the head of the talus is closely bound to the anterior process of the calcaneus (Fig. 26). This is visualized by the head being superimposed over a portion of the anterior process. The strength of this position is accentuated by the support of the sustentaculum tali, which may be observed as a summation of density when sufficient penetration has been allowed in this view. In this radiographic appearance, the length of the spring ligament may be appraised by the distance from the sustentaculum tali to the navicular (Fig. 27).

The talus is placed in a somewhat eccentric position on the calcaneus in that it rests in part on the sustentaculum tali. Due to the medial inclination of the neck of the talus, it seems to be obliquely positioned in reference to the calcaneus. The posterior facet of the subtalor articulations is almost centrally located in reference to the calcaneus, and the body of the talus is practically parallel with the long axis of the foot. Radiographically, the body of the talus is lost in the images of the superimposed leg structures; consequently, its position must be evaluated from the neck and the head of the bone.

The line that we have chosen for the long axis of the foot runs from the center of the posterior aspect of the calcaneus to a point midway between the second and third metatarsal heads. This line is relatively undisturbed by anatomical variations and mal-alignments of the foot, such as would be the case in Feiss's line, which follows the medial border of the foot and could be influenced by hallux valgus.

The establishment of centering points for this line gave rise to considerable study. Since the conventional dorso-plantar radiograph does not demonstrate the heel area, it would be impossible to indicate accurately a centering point, except by guess. The full-foot radiographic technique, in which the heel area is superimposed on a conventional dorso-plantar view, was developed to solve this problem. From this composite radiograph it is simple to indicate the long axis line.

In order to draw a line through the long axis of the neck of the talus, a point is marked at each of the extreme ends of the rounded head of the talus and a line drawn across This line is then bisected and a line drawn perpendicular to it This line is extended to the long axis of the foot The angle formed by these two lines represents the medial inclination of the head of the talus, which should be 15° under average circumstances. This angle seems to be the most significant measurement in appraising normal alignment of the talus to the calcaneus (Fig. 28).

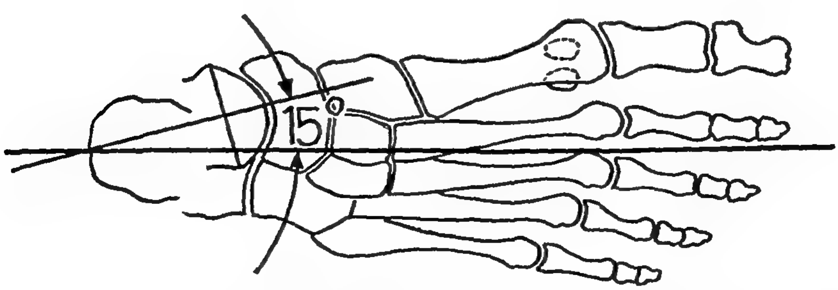


Fig. 28 Long Axis of Talus Neck Normally Inclined 15° from the Long Axis of the Foot.

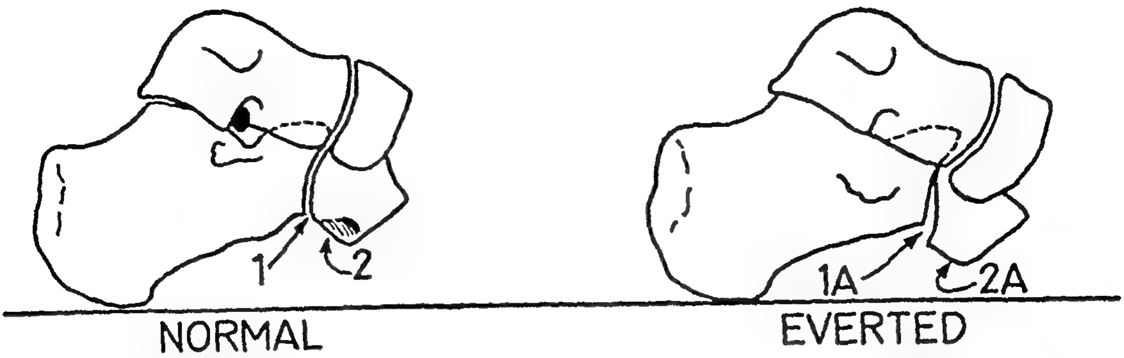


FIG. 31. INDICATIONS OF CUBOID POSITION. *Normal position:* (1) Plantar facets of calcaneo-cuboid joint are even, (2) peroneal groove is defined. *Everted position:* (1a) Uneven articulation of facets, (2a) density of peroneal groove lost.

wise position, with resulting loss of density to delineate it as such. When the calcaneus lowers in pitch, the cuboid follows to a lower plane, but the articular alignment is relatively undisturbed.

Radiographic Features of Normal Hindfoot and Mid-tarsal Joint Organization (Figs. 32, 33).

Lateral View

(1) Mid-tarsal joint line is a continuous cyma.
(2) Sinus tarsi is visible.
(3) Talus is parallel with weight-bearing plane (posterior process to center of head).
(4) Pitch of calcaneus should be uniform when both feet are studied.
(5) Pitch of calcaneus is an index of arch height.
(6) Subtalor space at posterior aspect indicates a level calcaneus.
(7) Plantar tuberosities of calcaneus are visualized by summation of density.
(8) Sustentaculum tali is defined as a dense thin line under head of talus.
(9) Cuboid articular facet is evenly aligned with calcaneus facet.
(10) Peroneal groove of the cuboid is delineated by added density.

Dorso-plantar View

(1) Mid-tarsal joint line is continuous.
(2) Head of talus is closely bound to anterior process of calcaneus.
(3) Length of plantar calcaneo-navicular ligament appraised from sustentaculum tali to navicular.
(4) Long axis of foot is from center of calcaneus to a point between the second and third metatarsal heads.
(5) Angle of medial inclination of neck of talus is 15°.
(6) 75 per cent of head of talus should articulate with navicular.
(7) Lateral border of calcaneus at its anterior portion lies parallel with long axis of foot.

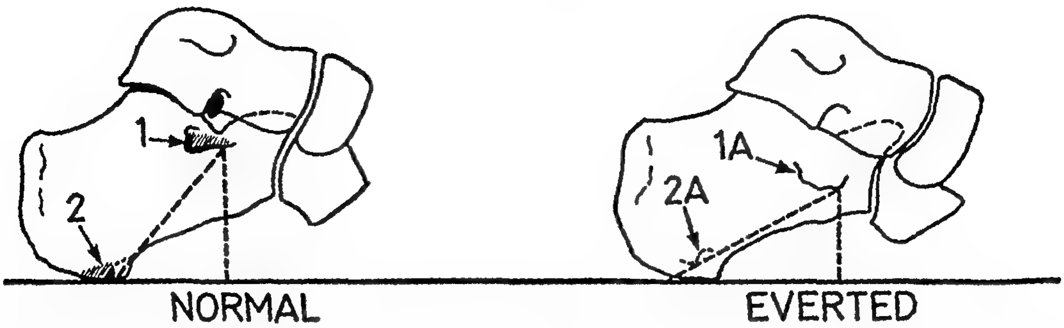


Fig. 30. Indications of Calcaneal Position. *Normal position:* (1) Density of sustentaculum tali sharply defined, (2) density of lateral tuberosity defined. *Everted position:* (1*a*) Broad, lower, indefinite outline of sustentaculum tali, (2*a*) Density of lateral tuberosity lost.

of the calcaneus. This is especially true when deciding what represents the true articular margin of the os calcis in following the continuity of the mid-tarsal joint. An excessive anterior process causes a false impression, whereas the calcaneo-cuboid joint should be followed as the accurate guide.

When carefully appraised, the tuberosities of the plantar aspect of the calcaneus indicate the normal position of the calcaneus. An increased summation of density defines the lateral tuberosity which is located slightly above the inner tuberosity when the bone is in proper position. When the bone is everted, the summation is decreased, indicating that the outer tuberosity is on a higher plane and demonstrating that a side-to-side tilt has taken place.

The radiographic visualization of the sustentaculum tali is another clue to the position of the calcaneus. In normal position, the lateral view reveals a thin line of little definition at the anatomical site for the sustentaculum tali. When the bone is everted, a broad area of density is observed. This indicates that the radiographic position of the bone has been altered to superimpose the sustentaculum tali over the main body of the bone, which would not be visualized under normal circumstances (Fig. 30).

In the dorso-planter view, the lateral border of the anterior portion of the calcaneus lies essentially parallel with the long axis of the foot. So little of this border of the bone is shown that it is not of much value in appraisal.

Relating the Calcaneus to the Cuboid. The cuboid is very closely articulate with the anterior portion of the calcaneus The ligamentous bond is very firm, and the articular facets of both bones are of almost equal size, which indicates small margin for joint movement. As long as the calcaneus maintains its normal position, the cuboid is properly aligned (Fig. 31).

Radiographically, the articular facet of the cuboid should match evenly with the articular facet of the calcaneus as visualized in the lateral view. The plantar prominence, which is anatomically accentuated by the groove for the peroneus longus, is visualized in the same manner as the calcaneal tuberosities In the case of the cuboid, added density delineates the prominence. When the calcaneus everts, the cuboid follows, and the plantar prominence assumes a side-

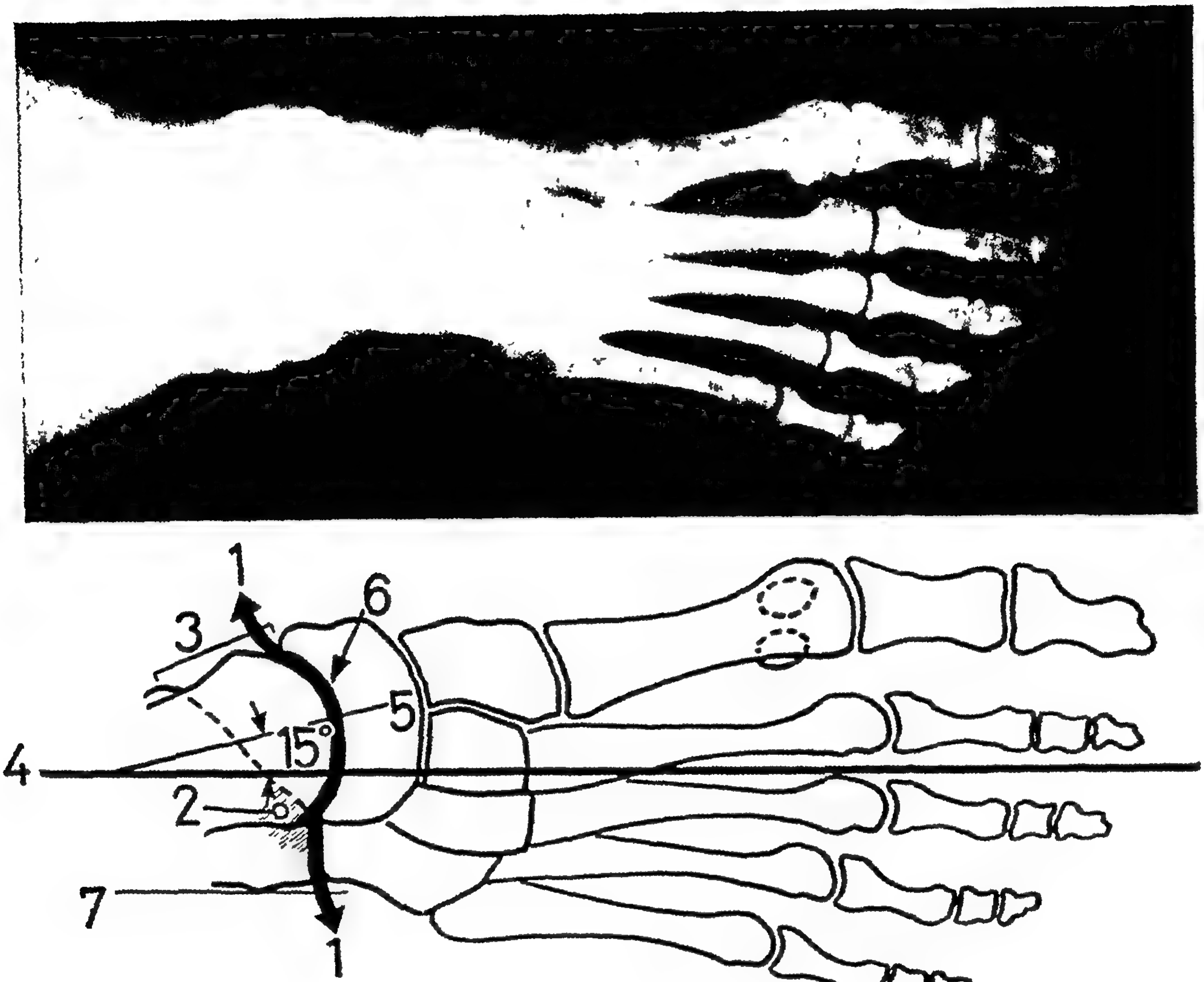


FIG 33. DORSO-PLANTAR VIEW. (1) Mid-tarsal joint line is continuous. (2) Head of talus is closely bound to anterior process of calcaneus. (3) Length of plantar calcaneo-navicular appraised from sustentaculum tali to navicular (4) Long axis of foot is from center of calcaneus to a point between the second and third metatarsal heads. (5) Angle of medial inclination of neck of talus is 15°. (6) 75 per cent of head of talus should articulate with navicular. (7) Lateral border of calcaneus at its anterior portion lies parallel with long axis of foot.

Figs. 32–33. Radiographic Features of Normal Hindfoot and Mid-tarsal Joint Organization

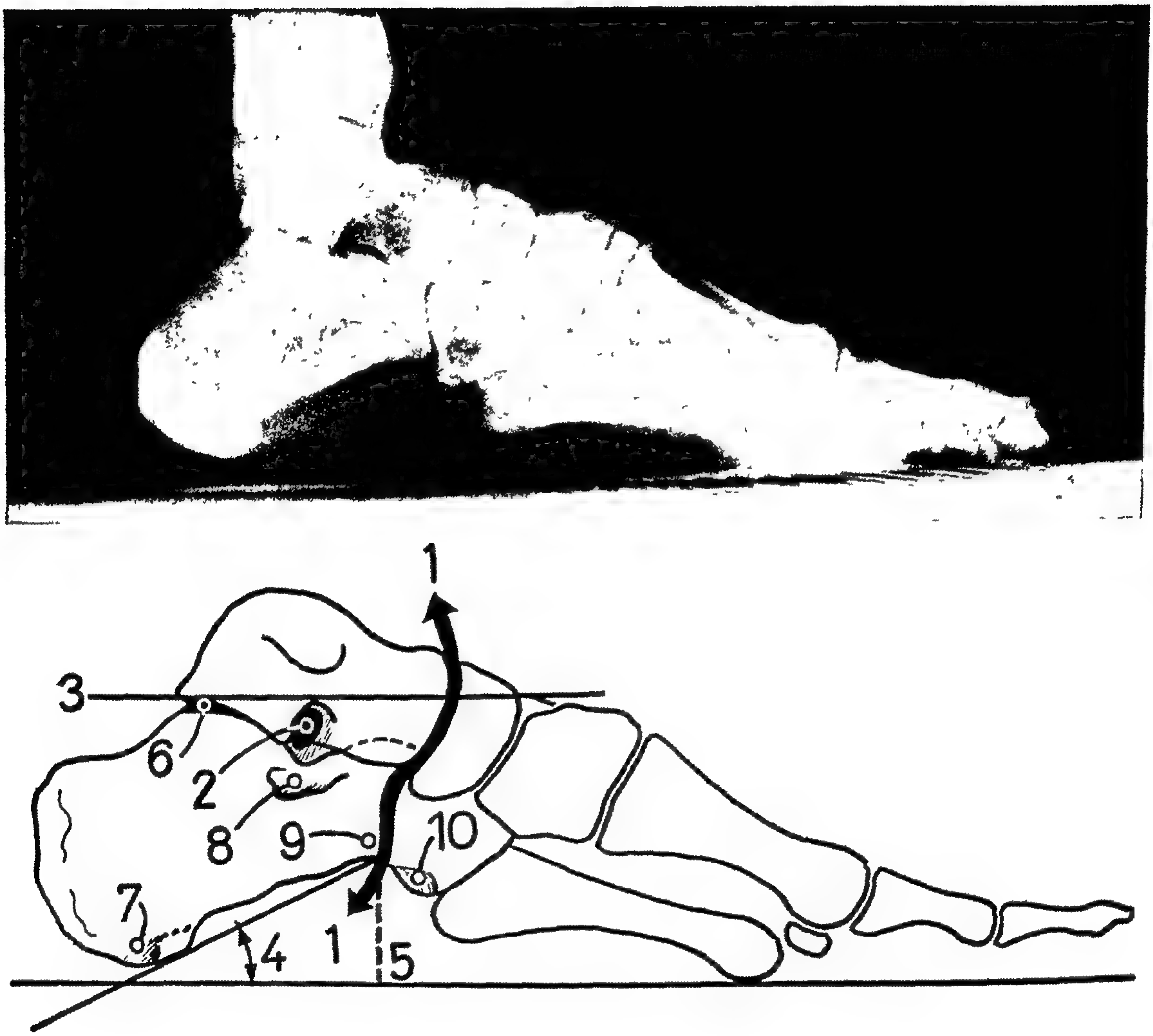


Fig. 32. Lateral View (1) Midtarsal joint line is a continuous cyma. (2) Sinus tarsi is visible. (3) Talus is parallel with weight-bearing plane (posterior process to center of head). (4) Pitch of calcaneus should be uniform when both feet are studied (5) Pitch of calcaneus is an index of arch height. (6) Subtalor space at posterior aspect indicates a level calcaneus (7) Plantar tuberosities of calcaneus are visualized by summation of density. (8) Sustentaculum tali is defined as a dense thin line under head of talus. (9) Cuboid articular facet is evenly aligned with calcaneus articular facet (10) Peroneal groove of the cuboid is delineated by added density

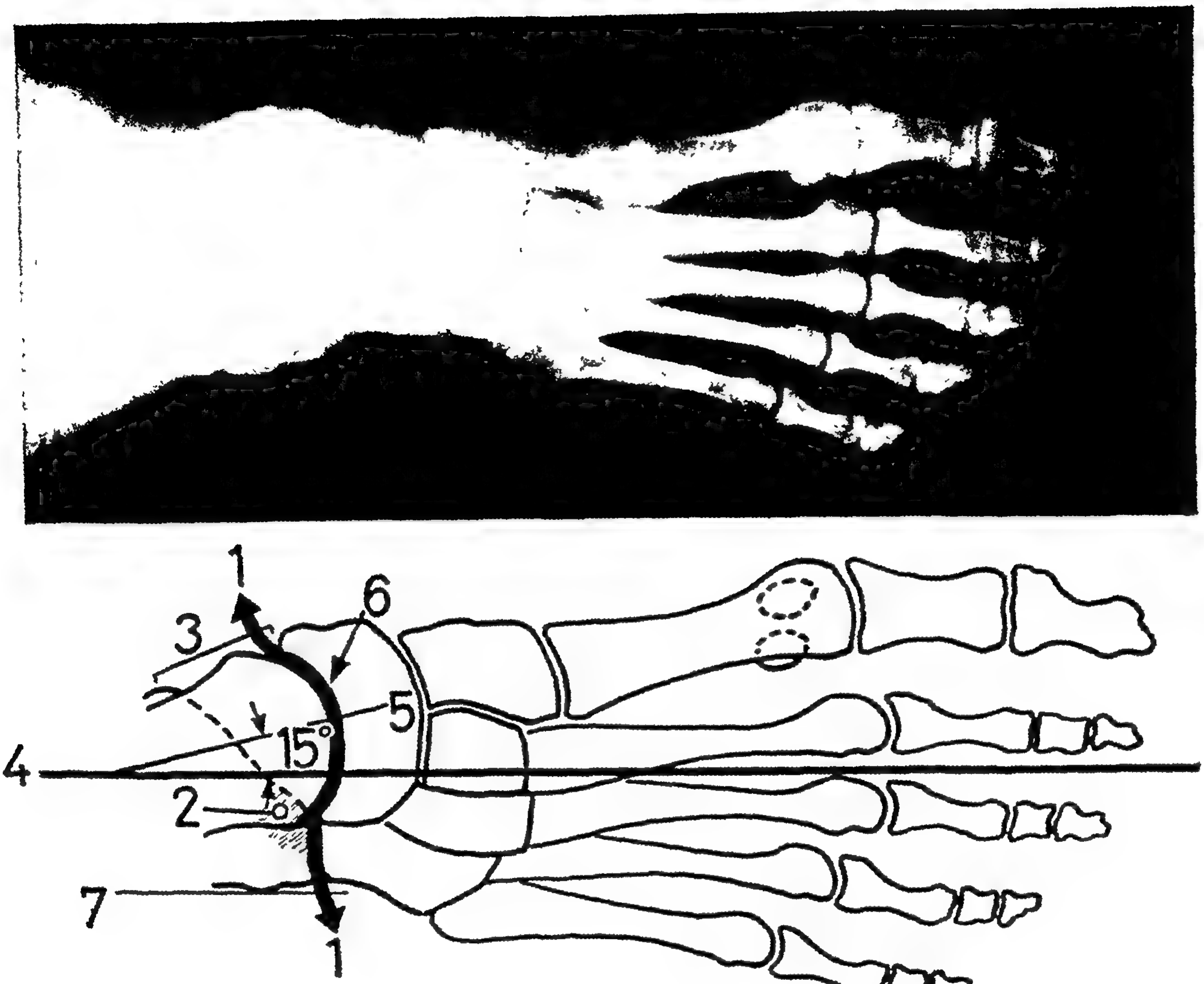


Fig. 33. Dorso-plantar View. (1) Mid-tarsal joint line is continuous. (2) Head of talus is closely bound to anterior process of calcaneus. (3) Length of plantar calcaneo-navicular appraised from sustentaculum tali to navicular. (4) Long axis of foot is from center of calcaneus to a point between the second and third metatarsal heads. (5) Angle of medial inclination of neck of talus is 15°. (6) 75 per cent of head of talus should articulate with navicular. (7) Lateral border of calcaneus at its anterior portion lies parallel with long axis of foot.

TARSO-METATARSAL DESIGN

Just as the hindfoot has a specific alignment for the greatest efficiency, the bones of the tarso-metatarsal area are designed by their arrangement to execute foot function and maintain maximum foot integrity. Several dominant structural patterns are included in this area: the forefoot segments of both medial and lateral longitudinal arches, the transverse tarsal arch, the metatarsal length pattern, and the phalangeal continuity.

Forefoot Segment of the Medial Longitudinal Arch. Anatomically, this segment consists of the navicular, three cuneiforms, and three metatarsals. Originating at the mid-tarsal joint, the posterior margin of the navicular forms a condyloid joint with the head of the talus, which supplies mobility to this joint. The anterior margin of the navicular articulates with the cuneiforms in an uninterrupted joint line. Less mobility is present in these arthrodial joints.

Radiographic Impressions

The lateral view describes only the medial aspect of the arch. The navicular should align evenly with the dorsal articulation of the talus at its superior margin and with the medial cuneiform at its plantar margin. The joint line of the medial cuneiform-first metatarsal base is directed obliquely toward the plantar aspect, following the inclination of the metatarsal bone.

The dorso-plantar view defines the alignment of the medial arch segment The transverse axis of the navicular is perpendicular to the long axis of the foot The medial border of the medial cuneiform is parallel with the long axis of the foot. The middle cuneiform is slightly oblique to the long axis of the foot, and the lateral cuneiform is almost obscured by superimposed images but may be visualized by its articulation with the navicular, which indicates that it is slightly oblique to the long axis. Alignment of the first metatarsal is slightly varus and that of the second and third is reasonably parallel with the long axis

The tarso-metatarsal joints are visualized in the dorso-plantar view in the following pattern. The first metatarsal bone should be in articulation with the medial cuneiform with the joint line almost perpendicular to the long axis of the foot. The second metatarsal base reaches deeply to the middle cuneiform and is couched in an articulation with the medial cuneiform on its medial border, an evenly aligned joint with the middle cuneiform at its posterior border and the third metatarsal base and lateral cuneiform on its lateral border. Radiographically, super-imposition of structures makes the lateral margin ill-defined. The third metatarsal articulates with the lateral cuneiform and again is not easily visualized except to assess the contour of the metatarsal base. The third metatarsal articulates with contiguous sides of the second and fourth bases. In visualizing the bases of the metatarsals radiographically, one must remember that the first is free, the second slightly overlaps the third, and the third overlaps the fourth. This aids in visualizing the arched arrangement of the bases.

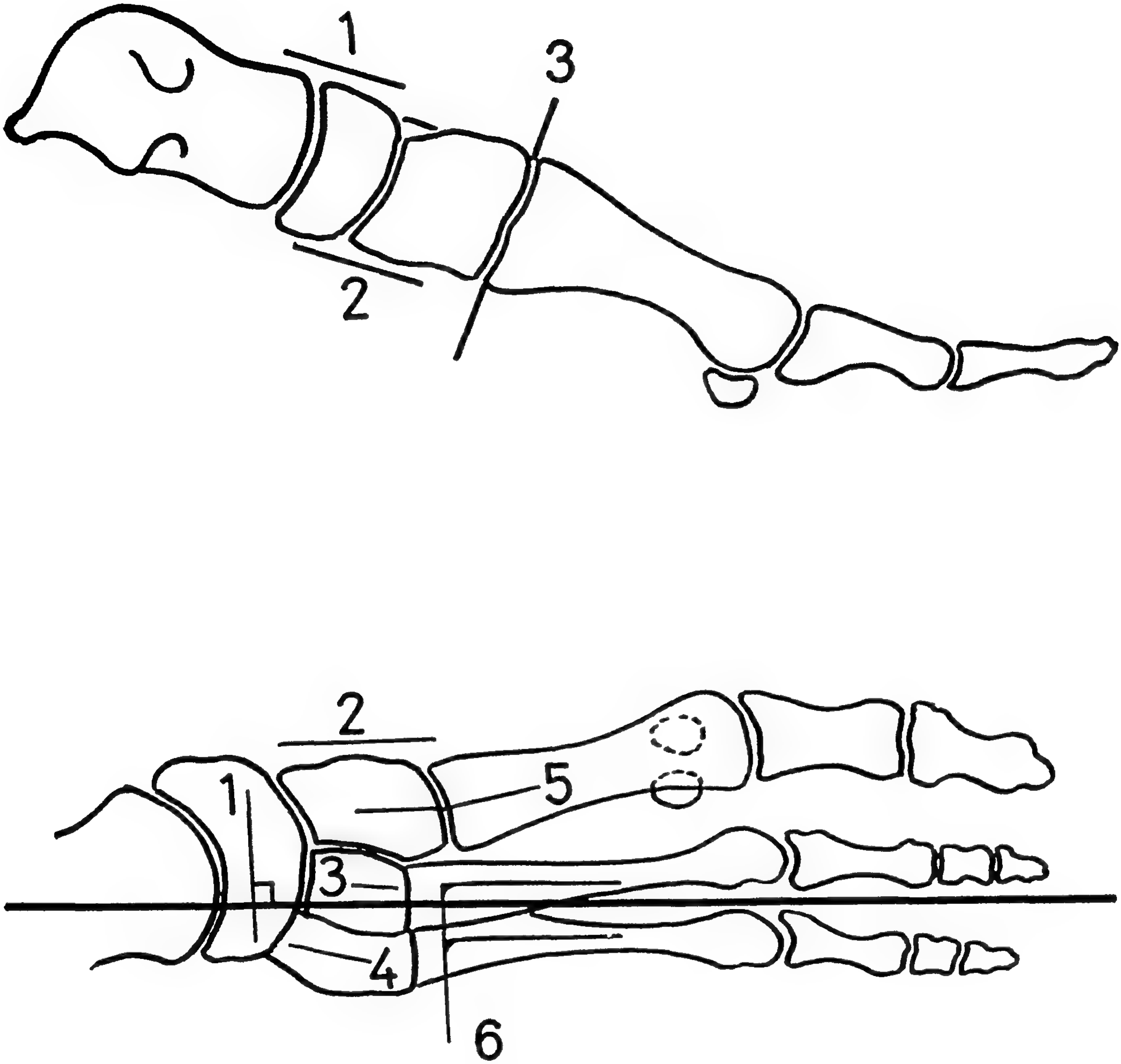


FIG. 34. RADIOGRAPHIC FEATURES OF NORMAL TARSO-METATARSAL DESIGN. FOREFOOT SEGMENT OF THE MEDIAL LONGITUDINAL ARCH. *Lateral view.* (1) Even dorsal alignment of head of talus and navicular. (2) Even plantar alignment of navicular and first cuneiform. (3) Oblique joint line of medial cuneiform and first metatarsal. *Dorso-plantar view.* (1) Navicular transverse axis is perpendicular to long axis of foot. (2) medial cuneiform, medial border is parallel to long axis of foot (3) Middle cuneiform is slightly oblique to long axis of foot. (4) Lateral cuneiform position is evaluated by articulation with navicular. (5) First metatarsal is aligned slightly varus. (6) Second and third metatarsals are reasonably parallel with long axis. (7) Tarsometatarsal joints: (a) First metatarso-cuneiform joint line is perpendicular to long axis of foot (b) Second metatarsal and middle cuneiform align as a segment. Middle metatarsal also articulates with first cuneiform and third metatarsal. (c) Third metatarsal articulates with lateral cuneiform and second metatarsal.

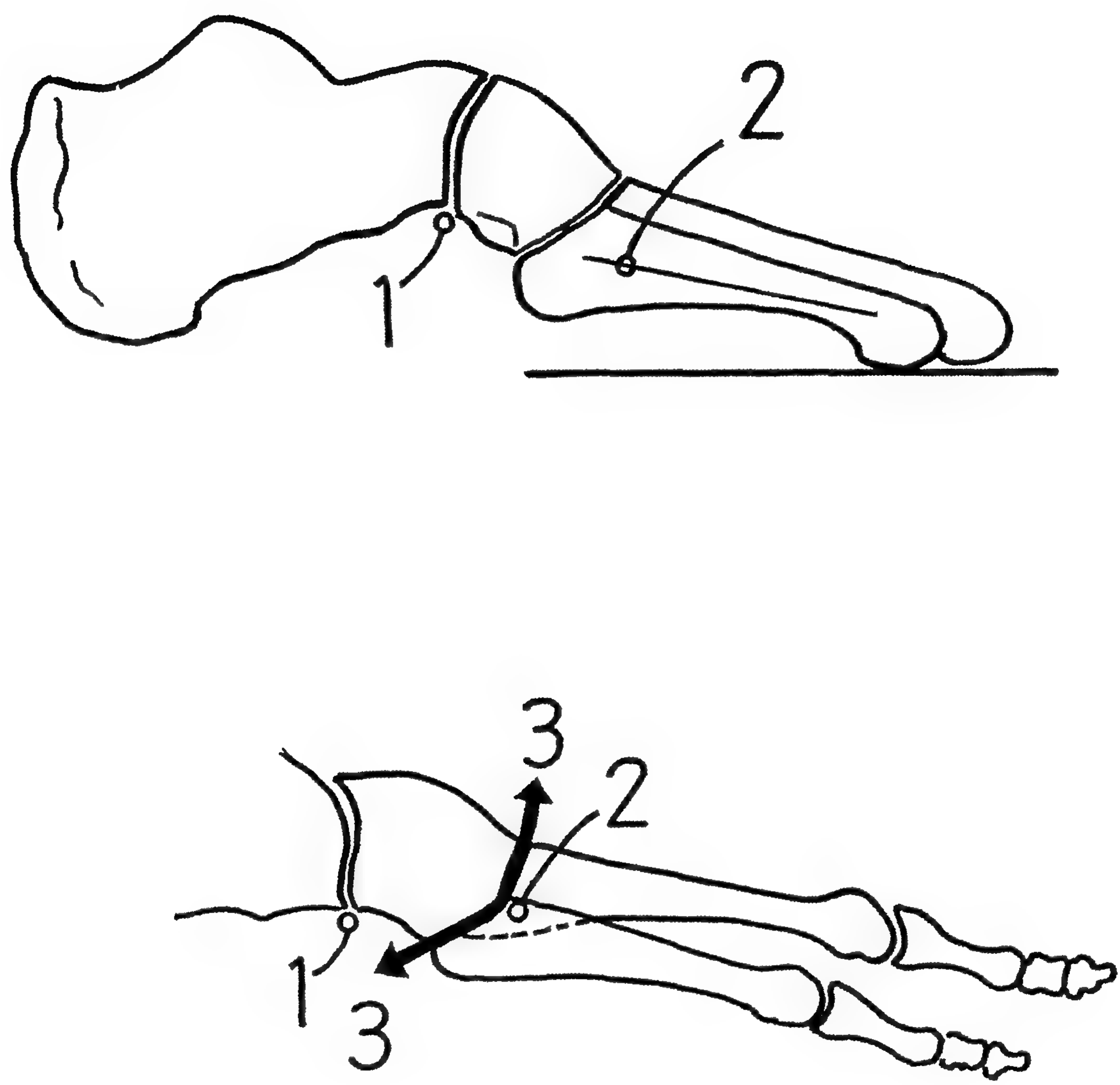


FIG 35. RADIOGRAPHIC FEATURES OF NORMAL TARSO-METATARSAL DESIGN. FOREFOOT SEGMENT OF LATERAL LONGITUDINAL ARCH. *Lateral view.* (1) Cuboid aligns with anterior portion of calcaneus. (2) Fifth metatarsal, plantar aspect, has plantigrade low pitch. *Dorso-plantar view* (1) Cuboid aligns with anterior portion of calcaneus (2) Fourth metatarsal articulates with cuboid and superimposes fifth metatarsal base by 50 per cent. (3) Fifth metatarsal base and tuberosity align obliquely with cuboid.

Radiographic Features of Normal Tarso–metatarsal Design. Forefoot Segment of the Medial Longitudinal Arch (Fig. 34).

Lateral View

(1) Even dorsal alignment of head of talus and navicular.
(2) Even plantar alignment of navicular and first cuneiform.
(3) Oblique joint line of medial cuneiform and first metatarsal.

Dorso-plantar View

(1) Navicular transverse axis is perpendicular to long axis of foot.
(2) Medial cuneiform, medial border is parallel to long axis of foot.
(3) Middle cuneiform is slightly oblique to long axis of foot.
(4) Lateral cuneiform position is evaluated by articulation with navicular.
(5) First metatarsal is aligned slightly varus.
(6) Second and third metatarsals are reasonably parallel with long axis.
(7) Tarso–metatarsal joints: (a) First metatarso–cuneiform joint line is perpendicular to long axis of foot. (b) Second metatarsal and middle cuneiform align as a segment. (c) Third metatarsal articulates with lateral cuneiform and second metatarsal.

Forefoot Segment of the Lateral Longitudinal Arch. This segment consists of the cuboid and the fourth and fifth metatarsal bones. The cuboid bone enters into a rather fixed saddle joint with the calcaneus at its posterior margin. This joint is visualized in both dorso-plantar and lateral views.

Radiographic Impressions

The anterior margin of the cuboid articulates with the bases of the fourth and fifth metatarsal bones. When the foot is properly aligned, the fourth metatarsal base superimposes the fifth metatarsal base by about 50 per cent of its width. The fifth metatarsal lies on a low pitch with the weight-bearing plane as seen in the lateral view.

Radiographic Features of Normal Tarso–metatarsal Design. Forefoot Segment of the Lateral Longitudinal Arch (Fig. 35).

Lateral View

(1) Cuboid aligns with anterior portion of calcaneus.
(2) Fifth metatarsal, plantar aspect, has plantigrade low pitch.

Dorso–plantar View

(1) Cuboid aligns with anterior portion of calcaneus.
(2) Fourth metatarsal articulates with cuboid and superimposes fifth metatarsal base by 50 per cent
(3) Fifth metatarsal base and tuberosity align obliquely with cuboid.

Relating the Medial Longitudinal Arch to the Lateral Longitudinal Arch. The dorso-plantar view of the forefoot does not make any distinction between the two arches by a clear-cut division of the two segments. One is superimposed on top of the other. Anatomically, the forefoot segments are joined in articulation at the lateral cuneiform-cuboid joint and at the base of the third metatarsal-fourth metatarsal base In an oblique view this very decided longitudinal division of the foot is easily visualized.

The lateral view of the forefoot discloses a superimposition of the arch segments The observer should establish the images of the medial longitudinal arch as the closer segment, because that is the way the images are recorded on the film in greatest detail.

The Transverse Tarsal Arch. Radiographically, the bases of the metatarsals provide the assessment in the visualization of the transverse tarsal arch If the metatarsals overlap in proper sequence at their bases, it may be assumed that the transverse tarsal arch is properly aligned. If it were flattened, the bases of the metatarsals would be spread apart, thereby indicating a loss of the transverse arch. This can be seen in the dorso-plantar view

Length Pattern of the Metatarsal Bones. Since Morton postulated his theory of primary foot disorder due to atavism of the first metatarsal, the relative length of the metatarsals has been brought into focus. More than ever before, investigators realize the importance of the joint line formed by the ends of the levers upon which the foot is raised during locomotion and upon which the forces of weight and gravity are imposed during standing.

Sansone refers to the arc formed by the metatarsal heads as a parabola, using architectural terminology Schuster suggested a method of measuring the arc by drawing a center line through the heads of the first, second, and fifth metatarsal bones and connecting these centering points to form an angle. Radiographs of 182 cases, performed at the Pomona survey were measured on this basis The mean angle was 142°. Schuster measured 97 cases with an average of 143°. Extremes ranged from 120° to 160°. From a practical standpoint, the flatter the curve of the parabola, the more even the length of the metatarsals. According to our evaluation, the normal length pattern should permit a hinge action through the metatarso-phalangeal joints that does not impose excessive forces upon any one metatarsal bone On a unit length basis, we found that the majority of cases presented a first metatarsal that was shorter than the second metatarsal, the third was shorter than the second; the fourth, shorter than the third; and the fifth, radically shorter than the fourth. This unit ratio of length is accepted as the normal pattern This ideal situation can occur only in a foot that qualifies in normal alignment, otherwise, the length pattern would be negated by other features of imbalance. Altered alignment causes elongation of the foot. This elongation occurs chiefly at the first metatarsal segment, thereby changing the metatarsal length pattern.

In spite of the most ideal lengths of the metatarsal bones, the actual distribution of weight upon the metatarsal heads is greatly influenced by the action of the toes. As soon as body weight is displaced to a position in front of the normal center of gravity, the great toes flex in an effort to maintain balance and direct weight transfer. The foot does not end at the metatarsal heads either in form or in function.

Much work has been done in evaluating weight distribution to the forefoot when the patient is in a static attitude. We accept the ratio presented by Morton: 2 units to the first metatarso-sesamoid area and 1 unit to each of the lesser metatarsals.

Radical discrepancies in the length pattern of the metatarsals will create specific weight-force problems when the foot is used on even surfaces in parallel gait. Henenfeld claims that it is possible to predict patterns of pivotal action and weight distribution in controlled situations of this kind. Features of weight distribution concern a variety of situations, according to the manner in which the foot is generally deployed; consequently, there is a great latitude for speculation.

The position of the sesamoid bones, which transmit weight forces under the first metatarsal head, is variable. In some instances, the variation visualized on the radiograph is due to geometric relationships performed by the central ray. Very careful standardization must be followed if any true evaluation is to be determined. In high-arched feet, the central ray will place the sesamoids closer to the metatarso-phalangeal joint than in low-arched feet. In view of these variables, it is unwarranted to place much reliance on this feature.

The side-to-side placement of the sesamoid bones should align the medial one under the metatarsal head just at its medial margin. The lateral one is situated partly under the lateral border and slightly in the interspace between the first and second metatarsal heads.

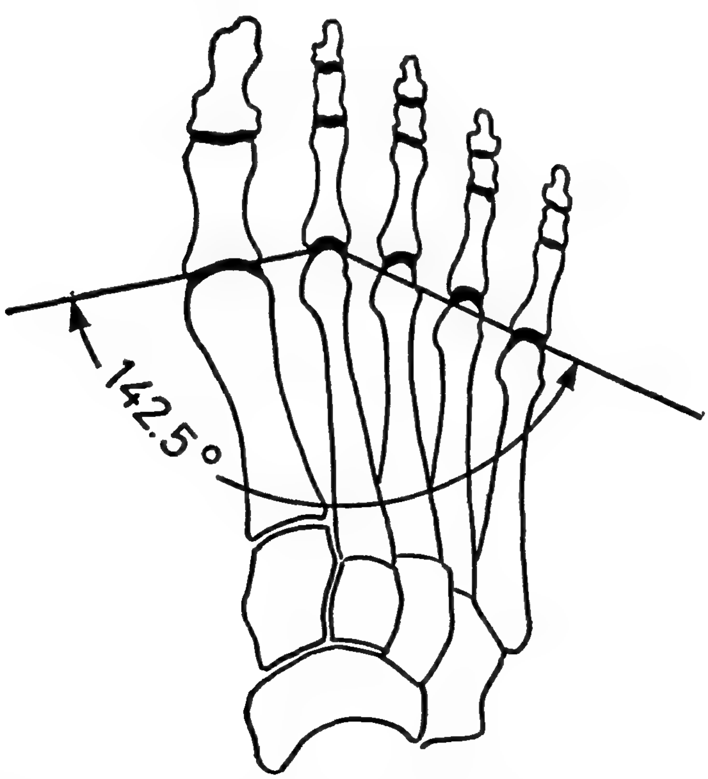


FIG 36 NORMAL LENGTH PATTERN OF METATARSAL BONES AT METATARSO-PHALANGEAL JOINT LINE *Dorso-plantar view*. (1) Total joint line angle 142 5° mean (2) First metatarsal is shorter than second (3) Second metatarsal is longest (4) Third metatarsal is shorter than second (5) Fourth metatarsal is shorter than third (6) Fifth metatarsal is shorter than fourth

Radiographic Features of Normal Length Pattern of Metatarsal Bones (Fig. 36).

Dorso–plantar View

(1) Total joint line angle 142.5° mean.
(2) First metatarsal is shorter than second.
(3) Second metatarsal is longest.
(4) Third metatarsal is shorter than second.
(5) Fifth metatarsal is shorter than fourth.

PHALANGEAL CONTINUITY

The phalanges of the toes follow the long axis of the metatarsal bones. This is observed in the dorso-plantar view. A slight flexion of the distal phalanges, which takes place in standing posture, creates a radiographic appearance in which the joint space between the middle and distal phalanges is obscured by overlap of these bones. A similar overlap may occur between the middle and proximal phalangeal joints. Joint space should always be demonstrated at the metatarso-phalangeal joints to indicate normal alignment.

The continuity of the toes is made possible by an intricate assembly of muscular elements extended to the toes by tendons that are precisely arranged in their attachments to the phalanges. In spite of the flexibility achieved in the several joints of the toes, the toes maintain straight alignment under normal circumstances.

ARTICULAR COMPOSITION

If properly approximated, the articular facets of the foot bones automatically align the foot in its authentic position when the individual assumes a standing position. The features pertain, of course, to the static attitude of the foot.

A critical appraisal of any foot joint should include a consideration of the following: type of joint, soft tissue related to the joint, articular cortex, articular cartilage, synovial membrane and joint capsule, joint space, bones entering into the complete articulation, surface area of the articulation of each bone entering into the joint, and alignment of articular surfaces.

Types of Joints Arthrodial: Talo-calcaneal, Cuneo-cuboid, Inter-cuneiform, Cuneo-navicular, Tarso-metatarsal, Inter-metatarsal Ellipsoid (Modification of Condyloid): Metatarso-phalangeal. Ginglymus: Inter-phalangeal.

Soft Tissues Related to the Joint. When we speak of the sinus tarsi and regard this anatomical landmark on the radiograph, we must realize that the sinus is filled with ligaments, fat, connective tissue, etc There are no unfilled cavities in articular arrangements in the foot.

Articular Cortex. The compact bone that forms the articular cortex helps delineate the joint margins.

Articular Cartilages. The cushion provided by cartilages for joint surfaces makes up a considerable proportion of the bulk of joint space. This may vary in amount in different individuals but it is of uniform consistency throughout all the foot joints.

Synovial Membrane and Joint Capsule. These elements are present in all joints but do not present an extensive radiographic appearance unless accentuated by pathological conditions.

Joint Space. The radiographic representation of all the soft-tissue constituents of the inter-articular space is demonstrated as joint space. Throughout all dimensions of the joint, this space should be uniform. If the space is diminished on one side and opened on the other, it is an indication of altered position of the bones entering the joint or of pathology of the actual joint constituents.

Bones Entering Into the Complete Articulation. Multiple articulations, such as the navicular-cuneiform articulations, are common in the foot. Since each bone is related to another in the articulation, they must be visualized in this spatial relationship.

Surface Area of the Articulation of Each Bone Entering Into the Joint. The shape and contour of the articulating surfaces of bones entering into a joint indicate the amount of motion that can be expected of that joint. The talus exhibits a facet on its postero-inferior aspect that is much larger than the corresponding facet of the postero-superior surface of the calcaneus; consequently, we may expect the talus to have a certain range of mobility on the calcaneus. The head of the metatarsal bones have greater articular area than the base of the phalanx. As a result, the range of motion follows the perimeter of the metatarsal head. The range of motion may be assessed by the radiographic appearance of the talo-navicular, first metatarso-phalangeal, and lesser metatarso-phalangeal joints.

Alignment of Articular Margins. In most joints of the foot, the facets are evenly aligned at their cortical outlines. This is demonstrated in the lateral view of the calcaneo-cuboid joint, in which the facets at the plantar aspect match evenly. This is an important radiographic feature, and any alteration should indicate mal-position.

Radiographic Features of Normal Articular Composition (Figs. 37, 38).

(1) Joint space should be uniform throughout the entire joint
(2) Alignment of articular margins at each end of joint should be even.

DOMINANT SHAPES PREVAILING IN FOOT BONES

Embryonic development of the foot bones presents a fascinating series of alterations. The initial differentiation sets up many more divisions of the primary anlage than ever become adult bones. Some of these unite to form a single bone; and still others persist to make up anomalies, supernumerary bones, and variations in bone shape. In the normal course of development, shapes of individual bones vary. Sewell points out that the talus originally has an elongated neck, which becomes shorter, and the transverse axis of the neck of the talus becomes more in line with the axis of the body. If the bones follow a normal pattern of development, they should reach maturity in the dominant form of usefulness.

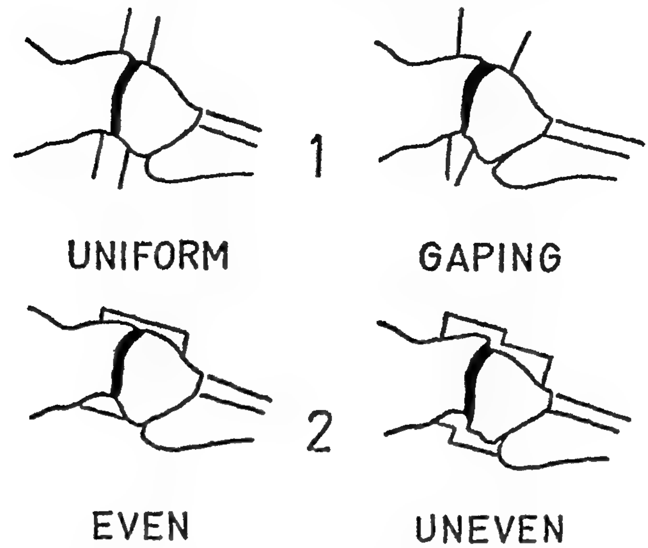


FIG. 37. RADIOGRAPHIC FEATURES OF NORMAL ARTICULAR COMPOSITION. (1) Joint space should be uniform throughout the joint. (2) Alignment of articular margins should be even.

The adult foot, which is the subject of our study, presents the final form of the bones, that is, the birth pattern as influenced by the laws of change of shape in response to function. No doubt many of the bone shapes that have been considered variations from normal shape are actually alterations of bone shape.

The strong foot is composed of bones that are shaped in a form that insures good structural ability and normal function. According to Pfitzner, bones with spicular projections are derived from physically imperfect individuals, and the strongest and best developed bones physically are not marked by sharp crests or tubercles but are smooth and round.

Dominant bone shapes, which emerge as the normal ones, prevail in the majority of feet. There are many minor variations and alterations that have no significant effect upon stability or function.

Descriptions of the individual bones will feature the dominant shapes as visualized on the radiograph. The reader should refer to a foot radiograph and follow the scheme precisely as each bone is outlined. The descriptions should also serve as a guide for the novice to follow in defining individual bones.

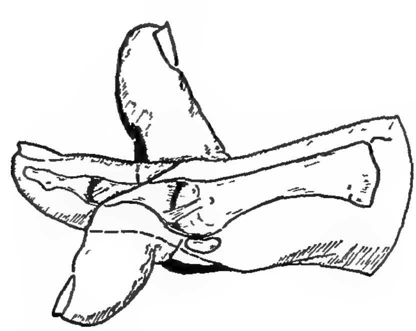


FIG. 38. RADIOGRAPHIC FEATURES OF NORMAL ARTICULAR COMPOSITION. Range of motion is shown by shape of articular surfaces

Radiographic Impressions

Calcaneus. The components of the calcaneus consist of the posterior body of the bone, the anterior process, and the sustentaculum tali. Following the shape of the bone as presented in the lateral view, a concave slope ranges from the supero-posterior articulation with the talus to the posterior border. The posterior aspect of the bone is somewhat irregular to receive the attachment of the tendo achilles. The plantar aspect demonstrates a small rounded surface of the medial tuberosity for weight-supporting contact. From this area, the plantar line of the bone describes a gentle concave curve to a point just short of the anterior tubercle, where it becomes convex until it abruptly curves to square-off for the vertical articulation of the anterior process. This process rises into a prominent area that is visualized as a sum of its density, over-shadowed by the head of the talus as it curves gently back to the level of the sustentaculum tali. The sustentaculum is visualized as a sum of density of this shelf-like projection and the entire width of the calcaneus. In some cases it is more distinct than in others. Posterior to the sustentaculum the calcaneus rises at an abrupt angle that represents the posterior articulation with the talus.

The dorso-plantar view reveals only the anterior portion of the calcaneus, visualized as a triangular-shaped area with its base articulating with the cuboid. A summation of density that shows the outline of the main body of the transverse section of the calcaneus to the sustentaculum tali may sometimes be visualized when the area has been well penetrated.

Strength is gained through the following: a shape consisting of well-contoured plantar tuberosities, a substantially-sized sustentaculum tali that is parallel to the weight-bearing plane, and an anterior process that is stocky and supplies an articulation for the head of the talus. The pitch of the os calcis at its inferior border should approach 30° for the weight to be easily distributed to the posterior element. Lower angles tend to permit the weight thrust to move toward the anterior element.

Talus. When viewed from the lateral position, the talus presents a body with a posterior tubercle, a neck, and a head. The superior surface of the talus is rounded into a gentle crown; the neck is narrowed just anterior to the line of the tibia; and the head presents a curved articulation with the navicular, which extends to a smooth roundness on its plantar aspect as it continues to the body of the bone.

The dorso-plantar view of the talus presents only the rounded head as it articulates with the navicular and the extended neck as it curves posteriorly and laterally over the anterior process of the calcaneus.

Although not visualized radiographically, the neck and head of the talus, as related to the body of the bone, lie on a slightly inclined plane when viewed as a segment at the mid-tarsal joint. For strength, the neck and head should be as nearly horizontal as possible.

Navicular. The lateral view of the navicular presents a rectangular shape with curved sides. The posterior margin articulates with the head of the talus, and the anterior surface articulates with the medial cuneiform. The dorsal articula-

tion is continuous with the head of the talus and slopes abruptly downward to articulate with the medial cuneiform. The middle cuneiform dominates the apex of this articulation and is deceptive in creating the impression that the dorsal curve of the articulation is even.

The dorso-plantar view demonstrates a curved rectangular-shaped bone, which is essentially as wide on its medial margin as on its lateral margin. At least three-fourths of the head of the talus articulates with the navicular at its posterior margin, and the medial and middle cuneiform articulations may be delineated anteriorly.

Cuboid. The posterior margin of the cuboid bone, as viewed in the lateral projection, is evenly aligned with the calcaneus, and its plantar tuberosity is dome-like in shape, separated by a summation of density that represents the groove for the peroneus longus. The anterior and superior margins of this bone are poorly defined, due to superimposition of other bones. The articulation of the fifth metatarsal bone with the cuboid, as visualized in the lateral view, does not show the joint space since the central ray does not pass directly through the articulation. At the posterior articulation, joint space is very definite, and the facets of the cuboid and calcaneus should be at the same level of approximation. If the facet of the cuboid is lower than the facet on the anterior portion of the calcaneus, it indicates that the cuboid is in a lowered position.

The dorso-plantar view of the cuboid bone also demonstrates a straight articulation of the anterior portion of the calcaneus with the cuboid. The lateral margin of the cuboid is curved, as it is a part of the groove for the peroneus longus. At the anterior margin, the fourth and fifth metatarsal bones are in articulation with the cuboid. The joint space is not distinctly delineated, but is of good proportion. When the foot is normally aligned and the cuboid is properly articulated with the calcaneus on its long axis, the fourth metatarsal base will be superimposed over the fifth metatarsal base. When the cuboid rotates, as it does in spreading and flattening of the foot secondary to valgus of the calcaneus, the fourth and fifth metatarsal bases are spread, so that, instead of considerable superimposition, the joint space becomes apparent at their articulation with the cuboid and also between the bases of the bones.

Medial Cuneiform. When visualized from the lateral view, the medial cuneiform is a third larger in size than the navicular, but of similar shape. The posterior articulation is contiguous with the navicular, and the dorsum of the bone rises abruptly from this joint, with the middle cuneiform in the background as a summation of density. The distal half of the bone is even on its dorsal margin and curves into the articulation with the first metatarsal base This margin of the bone is directed at an angle that is carried posterior to its inferior surface. This angle is important when we consider the radiographic appearance of this articulation from the dorso-plantar view, because the summation of density on the anterior portion of the medial cuneiform over the posterior and plantar portions of the first metatarsal creates a wedge-shaped appearance that is often mistaken by the novice for a metatarso-cuneiform wedge, when in reality it is a very normal appearance. The plantar margin of the medial cuneiform must be followed carefully to delineate it from summations of density of underlying

metatarsal bones. It follows a straight course posteriorly for three-fourths of the bone and then rises abruptly to meet its articulating surface with the navicular. When the entire body of the bone is viewed, a line is visualized running vertically about one-third of the distance posterior to the base of the first metatarsal. This line represents the base of the second metatarsal as it appears through the bone in summation of density.

The dorso-plantar view of the medial cuneiform presents an even and straight joint margin at its posterior aspect and a rather straight margin on the inner border, except for a prominence of varying size for the attachment of the tendon of the tibialis anterior. The anterior margin presents a confusion of joint lines, as is explained in the description of the lateral view of the articulation. The important joint line to visualize is the one that is most anterior, for it represents the dorsal aspect of the articulation of the medial cuneiform with the base of the first metatarsal. The joint margin adjacent to the base of the second metatarsal and middle cuneiform is very straight, and, under normal circumstances, the wide gap that may be visualized at this articular margin is not necessarily an indication of hypermobility of this segment. A gap of this articulation is more indicative of the norm than a closure of the joint space, since the latter situation would occur if the internal cuneiform were rotated on its long axis. In this case, a double summation of density would appear, indicating that the observer would be visualizing the medial face of the bone as it is presented obliquely to the central ray.

Middle Cuneiform. This bone is obscured in the lateral view by superimposition of other bones.

In the dorso-plantar view, the articular margin of the middle cuneiform with the navicular is well defined, and its obliquely faced medial margin is also well demonstrated. The articulation with the base of the second metatarsal is completely delineated.

Lateral Cuneiform. This bone is completely lost from visualization in both the dorso-plantar and the lateral views when the foot is normally aligned. Only when the transverse arch of the tarsals is flattened can joint space be observed at its articulation with the middle cuneiform.

First Metatarsal Bone. With the aid of average anatomical experience, the entire outline of the first metatarsal bone may be visualized in spite of the superimposed lines of varying densities which are caused by summations of other bony elements The dorsal aspect of the bone is usually in clear profile and follows a straight line to the head of the bone, where it rises sharply to the crown of the full margin of the articular surface of the distal end of this bone. The articular surface indicates the excursion of this joint On the plantar aspect, an ill-defined articulation is established for the sesamoids, and the margin extends posteriorly to a concave-shaped shaft that widens out at its base to meet the full articulation of the medial cuneiform bone. The posterior articulation rises obliquely, straight to the dorsum of the joint.

The dorso-plantar visualization demonstrates a basal articulation that is essentially perpendicular to the long axis of the bone The base of the bone bulges and the shaft narrows until it reaches the head of the bone. The medial margin

of the head of the first metatarsal is more rounded than the lateral margin. The distal articulating surface is gently curved.

Sesamoid Bones. Sesamoid bones are oval in shape and are occasionally bipartite. This may occur unilaterally.

Second Metatarsal. In the dorso-plantar view, this bone is completely demonstrated in profile, originating at its basal articulation with the middle cuneiform and tapering to a narrow shaft. It then widens to a rounded head, with condylar prominences present on either side of the crowned and rounded distal, articulating surface.

The summation of cortex density is demonstrated in the shaft of the bone.

Third Metatarsal. The base of the third metatarsal is couched between the second and the fourth, and the shaft is presented in profile. The head is similar to that of the second metatarsal.

Fourth Metatarsal. The base of the fourth metatarsal is couched between the third and the fifth, and its profile is the same as that of the third metatarsal.

Fifth Metatarsal. The fifth metatarsal presents a shape different from that of its adjacent members. In the lateral view, the posterior articulation extends obliquely to the tuberosity of this bone and then describes a concave shape to the very rounded head of the bone. The dorsal aspect is obscured by the superimposition of other bones.

The dorso-plantar view discloses an oblique articulation with the cuboid. This extends to the posterior tuberosity of this bone. The distal portion of the bone is similar to adjacent metatarsals.

Radiographic Features of Dominant Shapes Prevailing in Foot Bones (Fig. 39).

(1) Calcaneus. (a). Rounded posterior tuberosity. (b). Rounded plantar tuberosities. (c). Substantially–sized sustentaculum tali. (d). Parallel sustentaculum tali with transverse plane of sub–talor joint. (e). Moderately–sized anterior process.

(2) Talus (a). Rounded crown of body, no flattening or excessive posterior tubercle. (b) Definite neck–shape of talus not excessively long. (c) Substantially–sized head of talus has rounded head

(3) Navicular. (a). Rectangular–shaped. It is of approximately the same width on both medial and lateral aspects in the dorso–plantar view. (b) No excessive tuberosity to extend prominently on medial border of foot

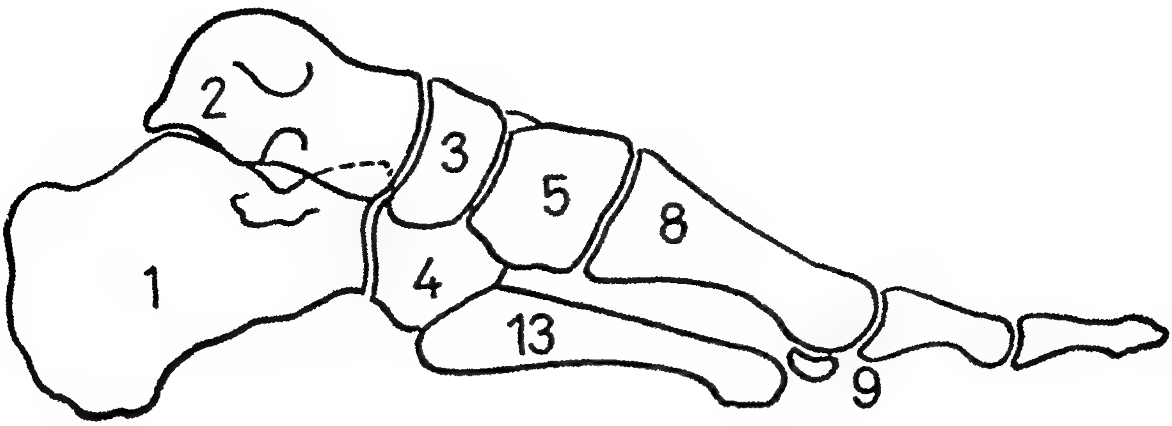
(4) Cuboid (a) Smoothly rounded plantar tuberosity with no excessive molding

(5) Medial Cuneiform (a) The anterior margin should be perpendicular to the long axis of the bone so that the base will set square in articulation

(6) Middle Cuneiform. Obscure

(7) External Cuneiform. Obscure.

(8) First Metatarsal Bone (a) Basal articulation margin perpendicular with the long axis of the bone to set square with internal cuneiform.



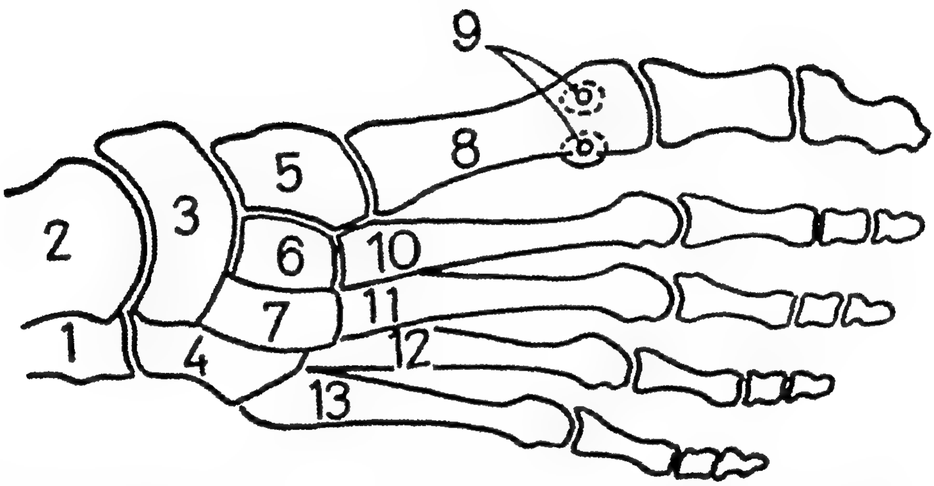


FIG. 39. RADIOGRAPHIC FEATURES OF DOMINANT SHAPES PREVAILING IN FOOT BONES. (1) *Calcaneus.* (a) Rounded posterior tuberosity. (b) Rounded plantar tuberosities. (c) Substantially-sized sustentaculum tali. (d) Parallel sustentaculum with transverse plane of subtalor joint (e) Moderately-sized anterior process. (2) *Talus.* (a) Rounded crown of body, no flattening or excessive posterior tubercle. (b) Definite neck-shape of talus is not excessively long. (c) Substantially-sized head of talus has rounded head. (3) *Navicular.* (a) Rectangular-shaped. It is of approximately the same width on both medial and lateral aspects in the dorso-plantar view. (b) No excessive tuberosity to extend prominently on medial border of foot. (4) *Cuboid.* (a) Smoothly rounded plantar tuberosity with no excessive molding. (5) *Medial Cuneiform.* (a) The anterior margin should be perpendicular to the long axis of the bone so that the base will set square in articulation. (6) *Middle Cuneiform.* (7) *External Cuneiform.* (8) *First Metatarsal Bone.* (a) Basal articulation margin perpendicular with the long axis of the bone to set square with the internal cuneiform. (9) *Sesamoid Bones.* (10) *Second Metatarsal.* (11) *Third Metatarsal.* (12) *Fourth Metatarsal.* (13) *Fifth Metatarsal*

(9) Sesamoid Bones. Oval.
(10) Second Metatarsal.
(11) Third Metatarsal.
(12) Fourth Metatarsal—head, shaft, and base.
(13) Fifth Metatarsal—head, shaft, base, and tuberosity.

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Chapter III

Acquired Fault Syndromes

Medical literature is replete with descriptions and classifications of arch depressions—descriptions that fail to narrow the problem down to the complete patho-anatomy involved in the specific areas of the foot that are vulnerable. The radiograph provides a means for assessing the osseous lesions on a meaningful, analytical basis. Disorders of the longitudinal arches are a sequel to various faults. These faults will be specifically described and evaluated on the basis of thousands of cases and their clinical evaluations that have been assembled over a period of 15 years.

When we examine radiographs of the disordered foot in a weight-supporting position, the various areas of structural entity exhibit certain patterns of change that occur with regularity. These typical alterations that develop as the foot changes in its structural stability, balance, and morphology may be referred to as fault syndromes. Our study indicates that there are three major faults: (1) Mid-tarsal Fault, (2) Navicular-cuneiform Fault, and (3) Calcaneo-cuboid Fault Also, D. J. Morton describes a syndrome related to atavism of the first metatarsal segment.

Recognition of the type of fault syndrome is a matter of becoming familiar with the features depicting each syndrome. It is, of course, possible for more than one fault to be present in the same foot. In fact, this occurs frequently, since one fault leads to another. Also, there may be some minor variation in the features presented by a syndrome because of individual foot discrepancies. However, this does not discount the predominant characteristics of the fault

Inherent bone shapes of faulty design contribute to structural weakness of the foot and will sometimes complicate the usual pattern of a fault syndrome. These faulty shapes will be described. Simple methods of recognizing exceptional shapes will be given so that the interpreter will not be misguided.

The patho-anatomy of the supporting ligaments and of the muscle systems are of necessity involved in every change of structure. Reference will be made to the vital features that are of interest to the diagnostician.

Clinical manifestations are associated with each fault syndrome. For example, forward displacement of the talus from the calcaneus invariably produces an inflammatory reaction that will elicit tenderness on palpation of this area while it is subjected to stress. It is apparent that the radiographic visualization of the features of the fault syndrome are meaningful when interpreted in connection with their true clinical import.

The three major foot faults usually result in a depression of the morphology of the longitudinal arches, however, the inherent foot imbalance that occurs is of equal interest to the clinician. Minor alignment changes in adjacent bones will be grouped and related to major fault syndromes. There will be a special discussion of alterations in bone shape caused by changes in function. Every effort will be made to give a practical consideration to both matters of interpretation and to clinical application, in order to enable the reader to use the radiographic study in an acceptable manner.

HINDFOOT AND MID-TARSAL FAULT

When the structural stability of the foot is impaired through some form of abuse, in due time there is a manifestation of mal-alignment of the foot struc-

Figs. 40–45. Comparative Study of Mid-tarsal Fault: Left Foot with Right Foot, Each Case. (Refer to these illustrations again after detailed study of the entire chapter.)

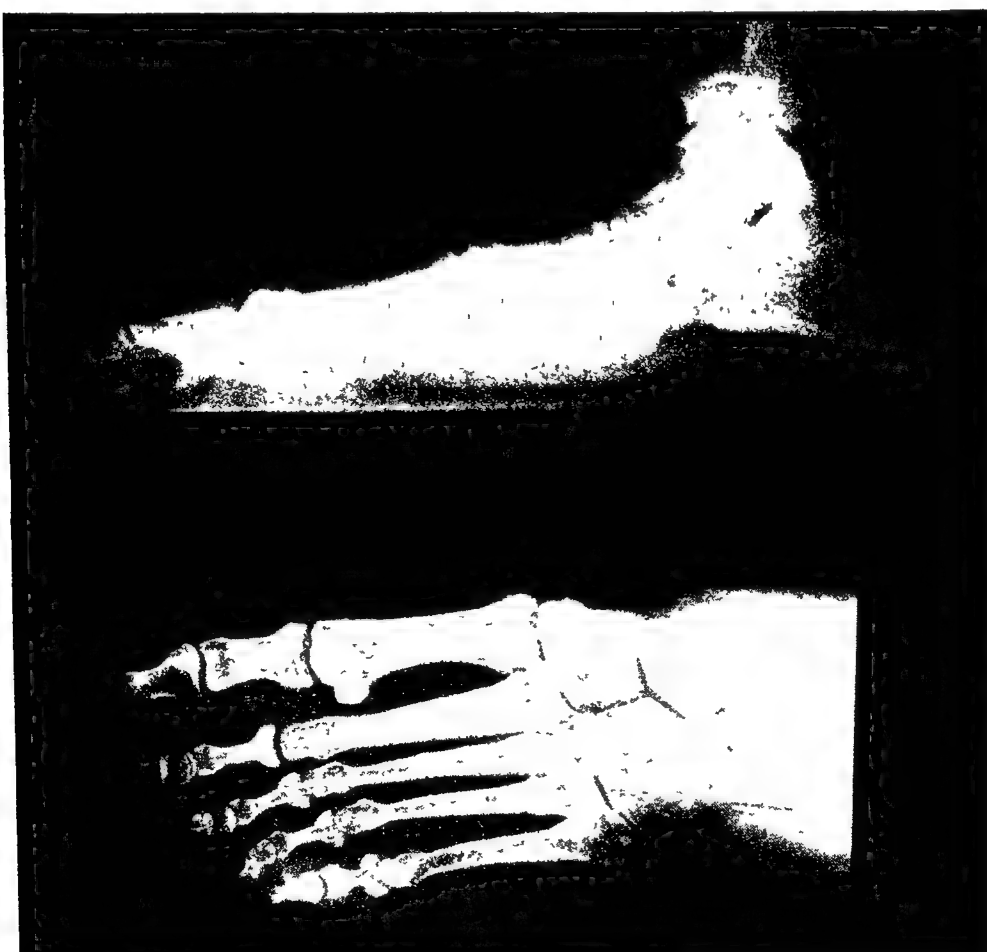


Fig 40 Left Foot Low Arch Type Mid-tarsal Fault Extreme degree, but less than in right foot

ture. This is due to the vulnerability of the ligaments that bind the bones together. The hindfoot, consisting of the calcaneus and talus, is the first area to demonstrate great change. These changes extend to the mid-tarsal joint. It is convenient to appraise this syndrome by describing the altered anatomy as visualized on the radiograph. Nutt has emphasized the importance of the mid-tarsal joint in the following statement: "Loss of the normal function of the mediotarsal joint is, I believe, the most frequent cause of foot complaints."

Radiographic Impressions

Lowering the Pitch of the Calcaneus: Lateral View. The angle formed by the plantar aspect of the calcaneus and the weight-bearing plane diminishes when the calcaneus is influenced by a contracted calf-muscle group or by an elongation of the plantar fascia and intrinsic foot muscles. This lowering in pitch is easily appraised when one foot of an individual demonstrates an advanced state of collapse as compared to the other foot. This provides an excellent control

FIG 41 Right Foot Low Arch Type Mid-tarsal Fault Extreme degree This case is a composite of every feature of the syndrome. Morton's syndrome is also present.

study (Figs. 40–45). Even the better foot of the two may be substantially altered from its original status when the foot was strong. In cases where the pitch is lowered bilaterally in equal degree, the observer may recognize this by noting that the anterior portion of the plantar tuberosity of the calcaneus is lowered into the principal weight-supporting area for the calcaneus. Normally, the mid-portion of the plantar tuberosity should carry the load, and a shift to the front indicates lowering of the calcaneus pitch. Clinically, the presence of spur-like calcifications at this point indicates the irritating forces acting on the periosteum, resulting from the new and unusual weight-bearing area, plus the stress developed at the attachment of the plantar fascia to the calcaneus. Calcifications frequently extend from the posterior aspect of the calcaneus superiorly at the attachment of the tendo achilles. Again, this is evidence of unusual stress, which at the same time pulls the bone into lowered pitch.

Since it is the pitch of the calcaneus that determines arch height, it is obvious that depression of the arches follows any lowering of the anterior part of this bone (Fig 46). The original normal arch height of a disordered foot can only be estimated on the basis of the severity of all the radiographic features

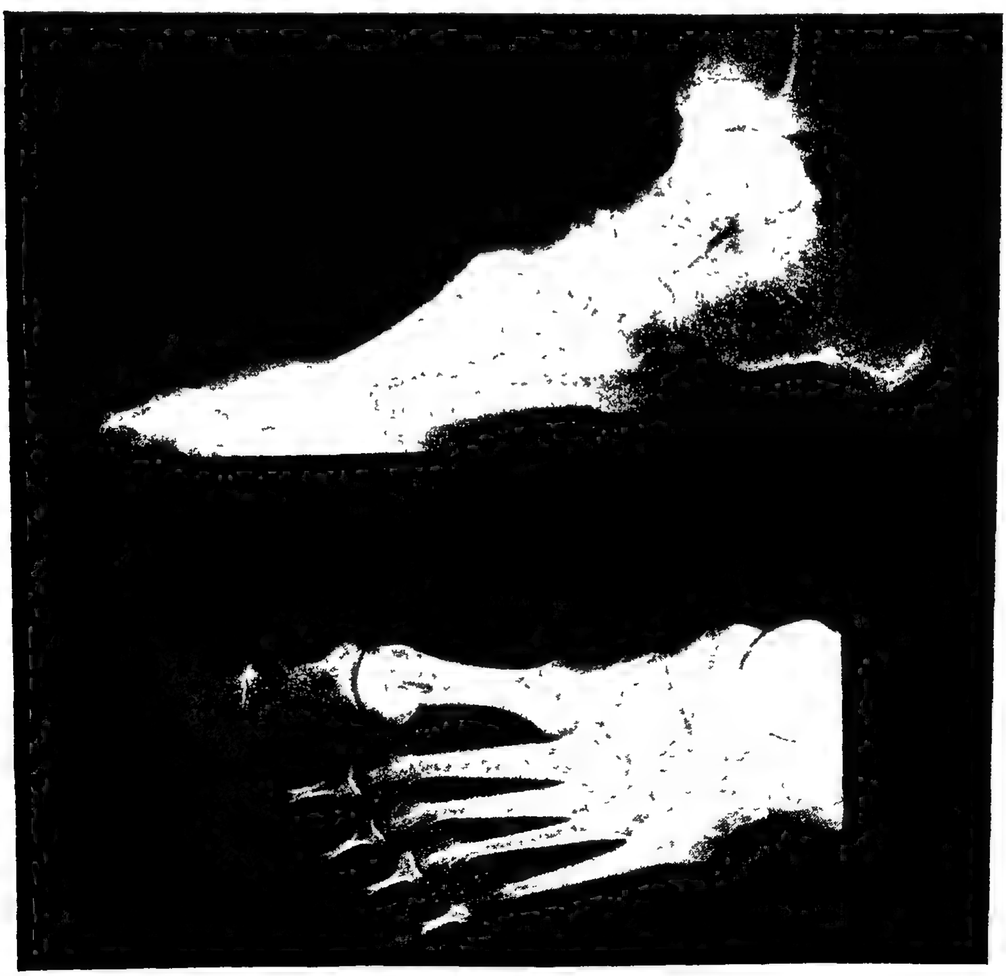


FIG. 42. Left Foot Medium Arch Type. Normal Hindfoot and Mid-tarsal Joint.

depicting the syndrome. Clinically, the medium arch height is more likely to exhibit fault than the high arch type or the low arch type. Architecturally, the high arch provides a column through the posterior body of the calcaneus. This column transmits weight conveniently in a normal manner. Furthermore, the vaulted structure permits plantar fascia and intrinsic foot muscles to have maximum strength through a short span. The low arch type of foot, because of the extremely low natural pitch of the calcaneus, allows little margin for further lowering. In all instances, the change in position of the subtalor joints depreciates the ability of the foot to maintain balance and initiates foot failure.

Eversion of the Calcaneus: Lateral View. The calcaneus rotates on its long axis when it changes position. Radiographically, this is difficult to appraise, except on the basis of the sustentaculum area of increased density being visualized on a much lower level than the subtalor joint line. Another radiographic indication is the appearance of the plantar tuberosities in which the density outline of the outer tuberosity is diminished and the inner tuberosity shows the principal profile.

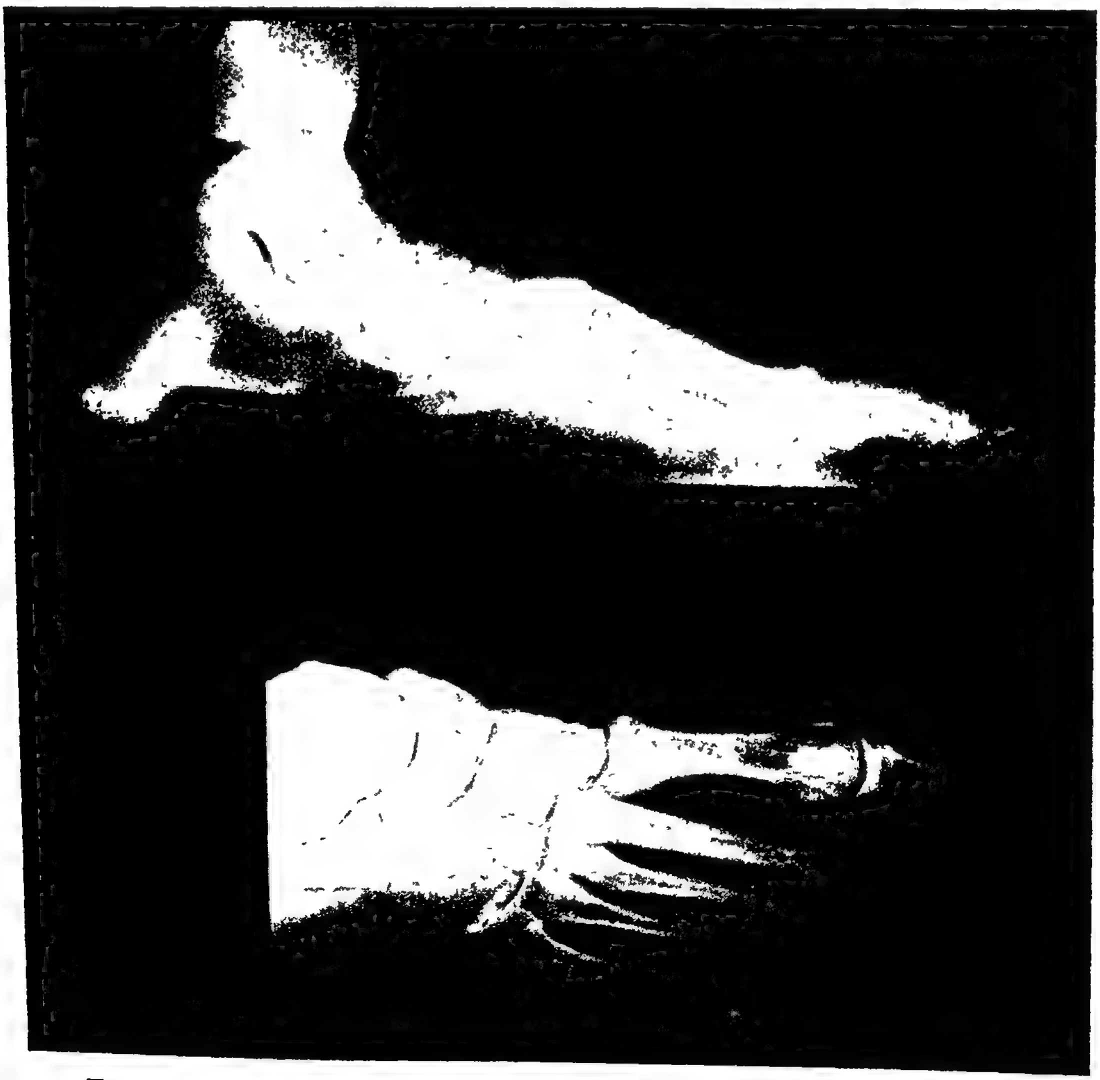


FIG. 43. Right Foot. Medium Arch Type Mid-tarsal Fault. Severe degree

Clinically, the eversion of the calcaneus contributes further to the abuse of the weight-bearing inner tuberosity. Of prime importance is the lowering of the sustentaculum tali balancing shelf which permits the talus to yield to gravitational forces, thereby setting the stage for further collapse. Grossly, the foot assumes pronation

Valgus of the Calcaneus. The true valgus position of the calcaneus in relation to the long axis of the foot is not discernible upon the radiograph.

Distal and Plantigrade Displacement of the Talus: Lateral View (Fig. 47). Since the talus is a passive bone with no muscular attachments, it follows the line of least resistance when its supporting subtalor joint areas assume a different plane and when the ligament tissues elongate to permit an altered excursion from normal.

Lowering of the pitch of the calcaneus with eversion accentuates the eccentric position of the talus so that it glides forward to the extreme limit permitted by the ligaments The head of the bone pivots downward as it slides beyond the

Fig 44 Left Foot High Arch Type Normal Hindfoot and Mid-tarsal Joint.

optimum support of the sustentaculum tali. There is ample room for this movement in the sinus cavities of the subtalor joint. The radiographic superimposition of the talus over the anterior process of the calcaneus emphasizes the changed position. The actual overlap of the talus over the anterior process of the calcaneus can deceive the observer if the process is of exceptional shape.

When downward displacement occurs, the approximate parallel plane of the talus, as exemplified by a line drawn from the center of the posterior process to the center of the head of the talus, assumes a distinct angle with the weight-bearing plane.

Clinically, the forward and downward displacement of the talus causes elongation of the foot, often referred to by the patient as foot growth. The need for longer shoes over a long period of time indicates the chronicity of the problem.

Medial Rotation of the Talus: Dorso-plantar View (Fig. 47B). Any forward and downward movement of the talus is usually accompanied by medial rotation of the talus. This results from the weakness of the ligamentous integument

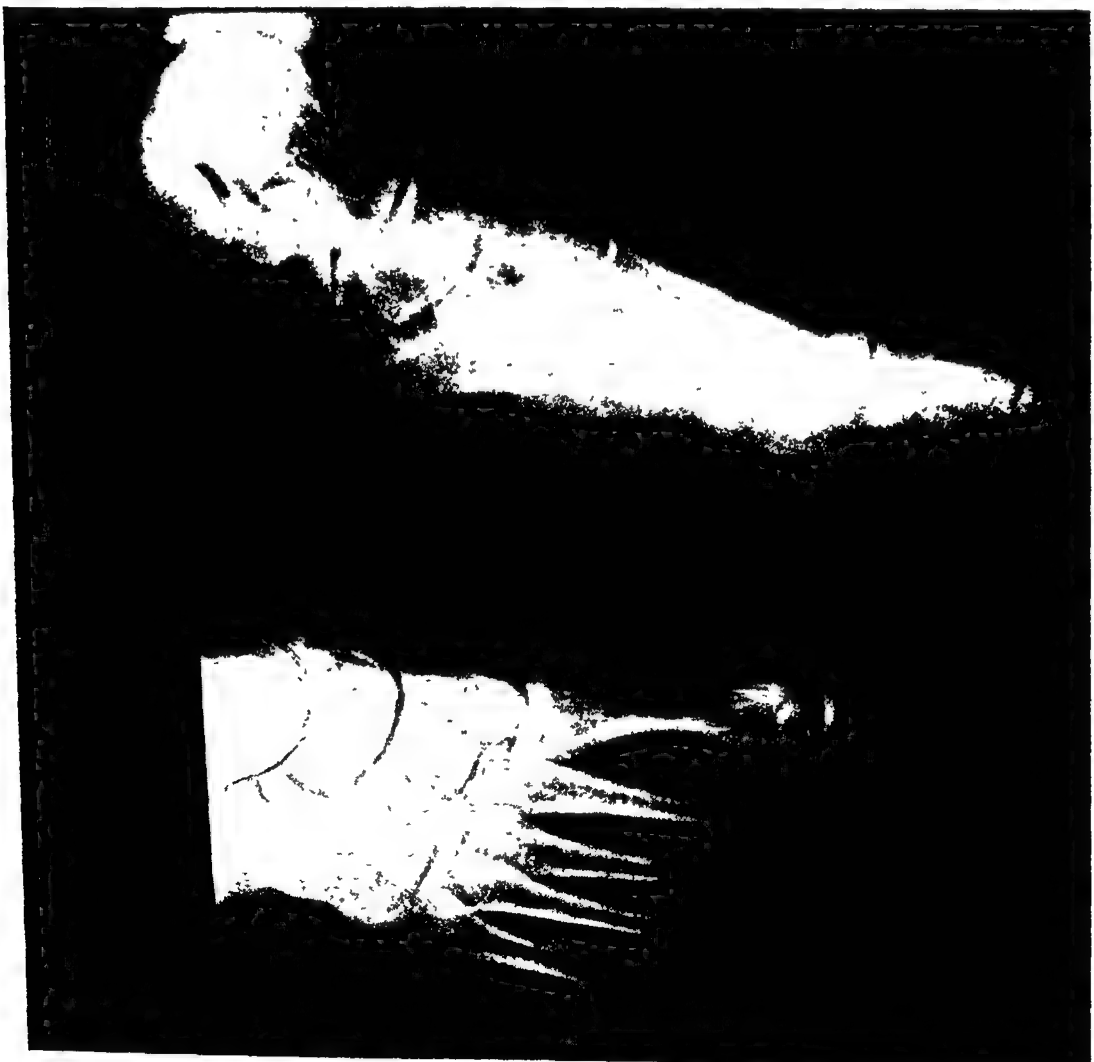


FIG 45 Right Foot. High Arch Type. Mid-tarsal Fault Medium degree

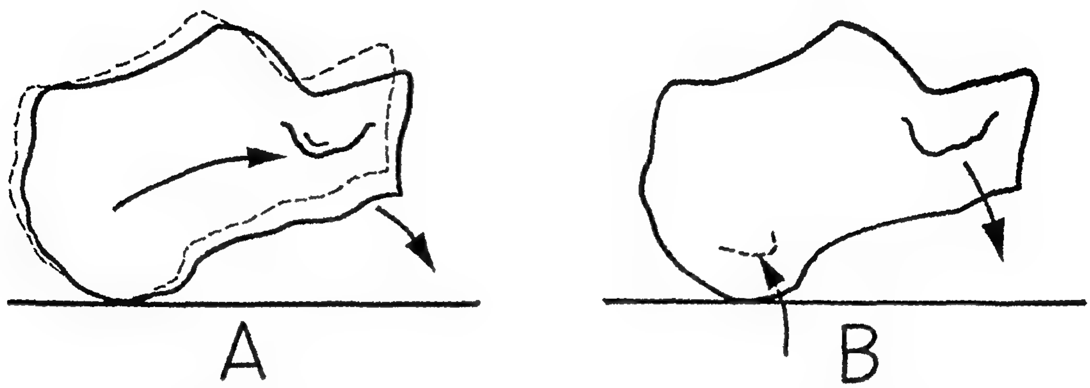


FIG 46. INDICATIONS OF ALTERED CALCANEAL POSITION. (a) Pitch of calcaneus lowers, (b) calcaneus is everted.

and the unstable subtalor articulation. The condyloid talo-navicular joint facilitates the alteration.

Radiographically, the talus becomes loosely bound to the anterior portion of the calcaneus according to the degree of rotation. The normal overlap of the head of the talus over the anterior process of the calcaneus diminishes, and in severe cases a gap exists at the junction point, indicating a complete lack of support. This looseness creates an increased width from the lateral margin of the calcaneus to the medial margin of the talus. This may be conveniently measured in comparing the discrepancy between both feet.

A more elaborate means of evaluating this medial rotation consists of drawing a line through the long axis of the talus and comparing it with a line drawn through the long axis of the foot. The medial inclination should not exceed 15°. A further critical evaluation may be made by measuring the length of the talus in the lateral view and comparing this measurement with the length of the talus of the other foot. The shorter measurement indicates a geometric shortening caused by the relationship of the rotated bone to the central ray.

Perhaps the most practical assessment is based on the fact that 75 per cent of the head of the talus should articulate with the navicular; consequently, when the talus has rotated medially and a smaller percentage makes articulation, we can evaluate the change (Fig. 48).

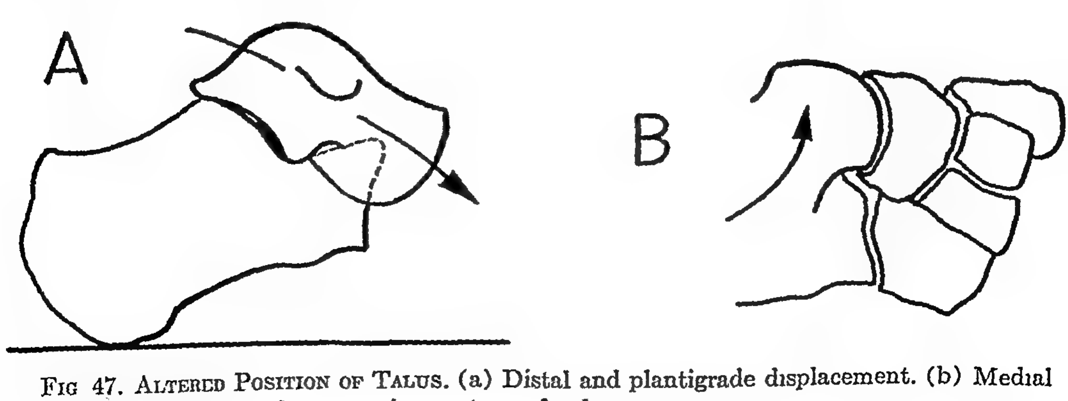


FIG 47. ALTERED POSITION OF TALUS. (a) Distal and plantigrade displacement. (b) Medial rotation Loosely bound to anterior portion of calcaneus.

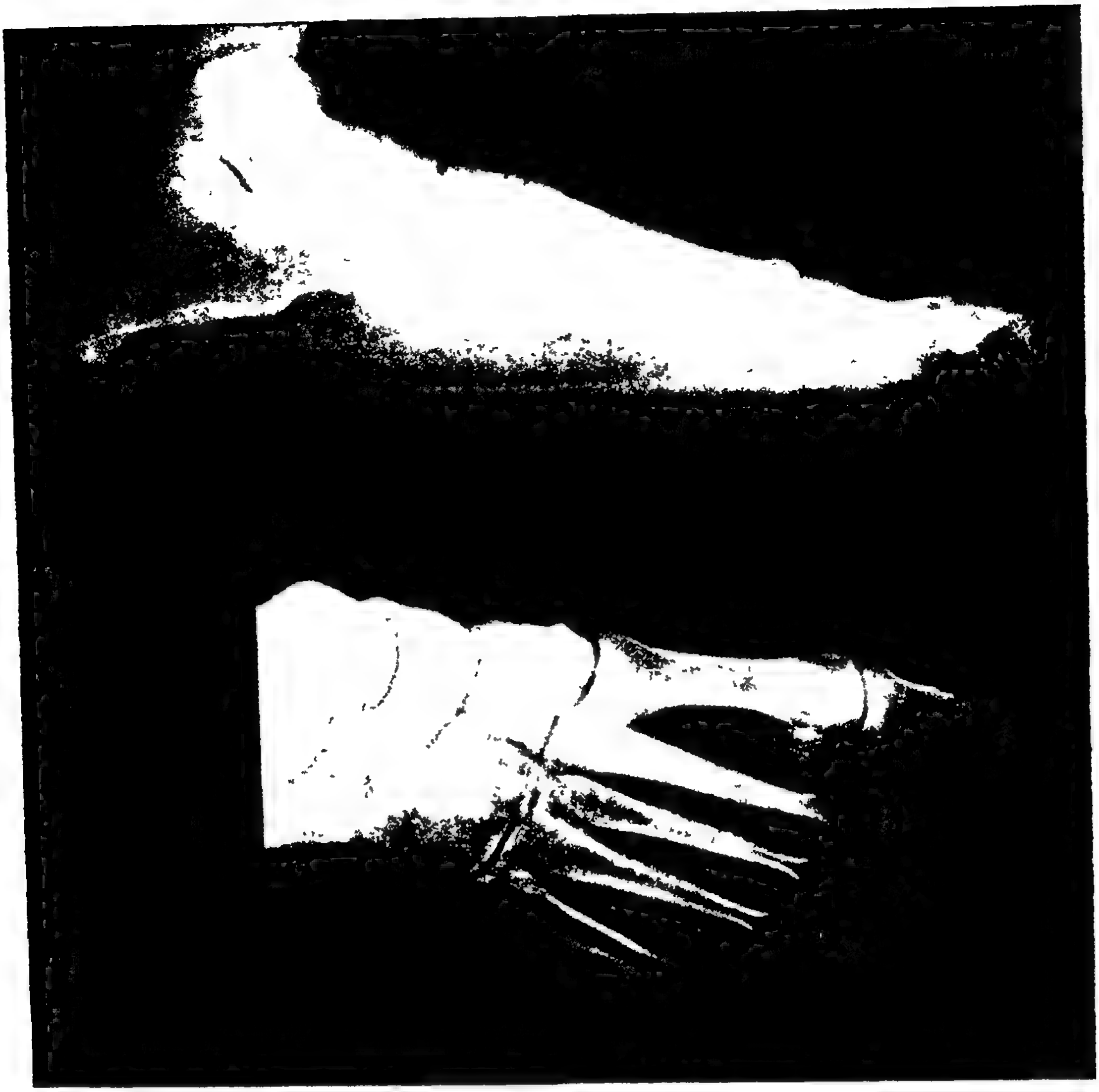


FIG. 48 SEVERE MEDIAL ROTATION OF TALUS. Creates pseudo-normal mid-tarsal joint line. Turned talus is fore-shortened in lateral appearance. Gaping space at midfoot junction of talus and calcaneus indicates loose binding Only 50 per cent of talor head articulates with navicular.

Clinically, the bulging head of the talus on the medial border of the foot is often mistaken for a tibiale externum and is also responsible for the so-called double-ankle effect in the disordered foot of a child.

Diminished Sinus Tarsi: Lateral View (Fig. 49A). The most positive demonstration of the changed position of the relationship of the calcaneus and talus is visualized in a diminution of the space normally visualized for the sinus tarsi. As the calcaneus lowers into eversion and the talus slides forward and downward and rotates medially, the large sulcus becomes closed The standardized lateral radiograph provides the index of this change. In some cases the sinus tarsi is completely obliterated.

The anatomical constituents of the sinus tarsi are not lost when the sinus diminishes; rather, the talo-calcaneal ligaments and other tissues are twisted to follow the course of the talus. It is the relationship of the central ray to the bones that fixes the imbalanced position so definitely.

Pseudo Sinus Tarsi: Lateral View (Fig. 49B). Often, in severe and extreme cases, the talus makes such a complete rotation and forward tilt that the posterior subtalor articulation appears to open up into an enlarged sinus, posterior to the sustentaculum tali. This opening is created by the central ray and is another excellent demonstration of the changed relationships of the hindfoot bones. Do not confuse the pseudo sinus with the normal appearance that should be anterior to the sustentaculum tali.

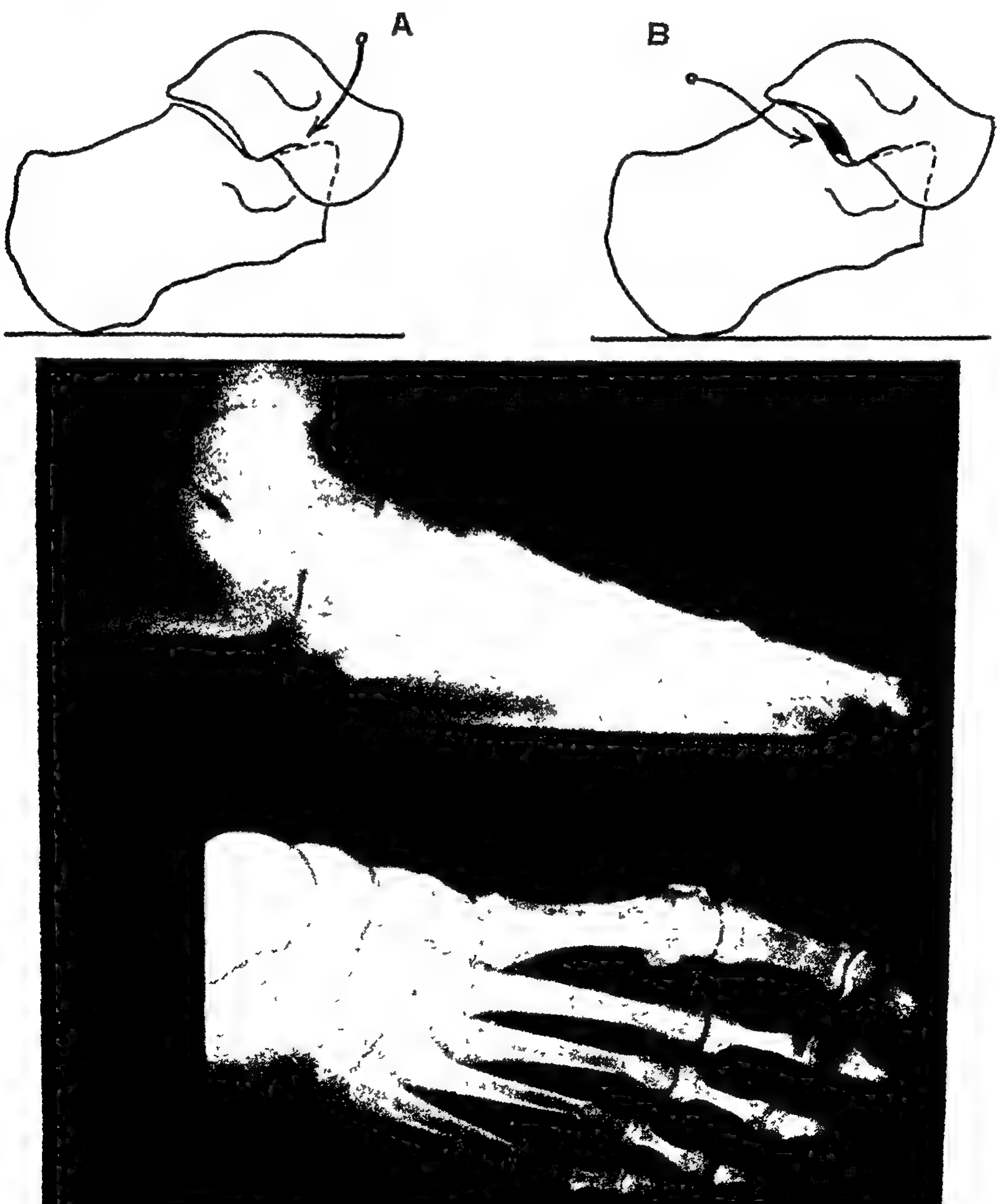


FIG. 49 SINUS TARSI. (a) Diminished or obliterated from view (b) Pseudo sinus tarsi, created in posterior subtalor joint space

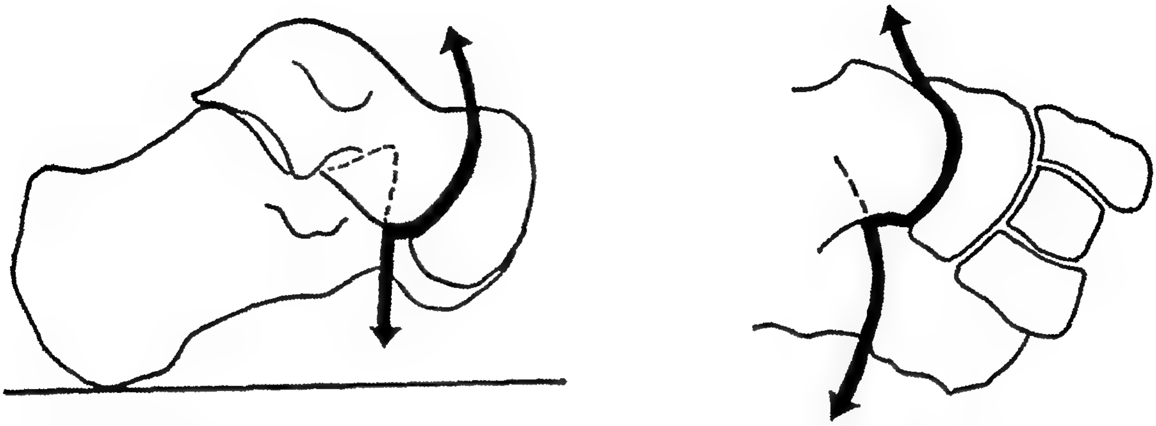


FIG 50. ALTERED MID-TARSAL JOINT LINE. The continuous cyma is broken. Calcaneo-cuboid joint remains fixed. The talus moves changing the line.

Altered Mid-tarsal Joint Line: Lateral and Dorso-plantar View (Fig. 50). The continuous curved line that ideally separates the hindfoot bones from the forefoot bones, the navicular and cuboid, is necessarily altered when the calcaneus permits the talus to move forward and downward. The joint line formed by the calcaneo-cuboid joint remains relatively constant in spite of the changed position of the calcaneus. There is some anterior tilting of the joint as the calcaneus lowers in pitch, and the cuboid moves as a unit with the calcaneus as it everts because of the strong ligamentous bonding of this joint. In both instances the movement is not appreciably demonstrated on the radiograph. This fixed line provides a means of assessing the more movable talus. In the lateral view, the talus juts forward beyond the calcaneo-cuboid joint line in proportion to its forward advance. This is delineated best when the central ray has been directed through the parallel margins of the joint; hence, the emphasis placed upon this centering point in the lateral technique.

From the dorso-plantar aspect, we may visualize the same distal projection of the head of the talus beyond the fixed calcaneo-cuboid joint line. It is important to take into account the fact that the more the head of the talus rotates medially, the less forward advance is likely to be developed. Hence, in severe cases of imbalance, we are likely to notice less alteration of the joint line than in moderate cases.

Cuboid and Navicular Reactions (Fig. 51). Accompanying the change in the the mid-tarsal joint line, we find the articulating bones of the forefoot responding to certain changes. The cuboid, as has been stated, is held in very close articulation with the anterior process of the calcaneus and usually follows the course of the calcaneus as it lowers in pitch. The articular space may remain uniformly spaced in this change. The chief alteration is the rotation of the cuboid on its long axis following the eversion of the calcaneus. The lateral view demonstrates this rotation in the loss of appearance of the groove for the peroneus longus, which is normally seen as an area of increased density.

Clinically, the rotation of the cuboid of which there is such scant radiographic evidence, is frequently the source of considerable pain and functional disability. The so-called "dropped cuboid" is technically a rotated cuboid, al-

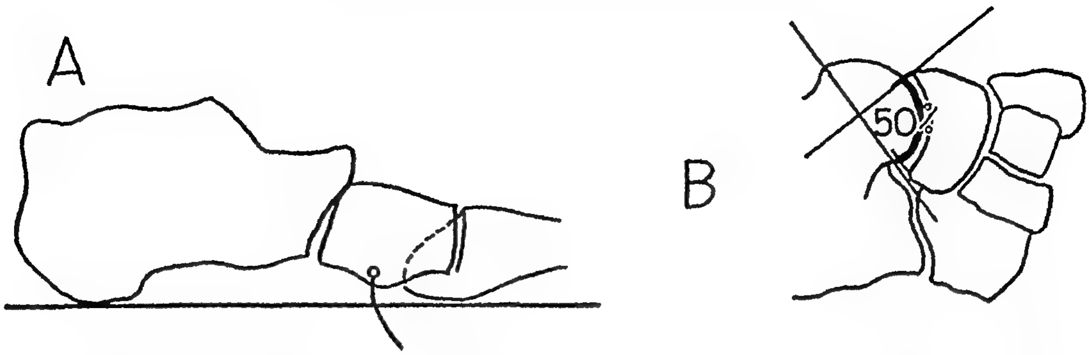


FIG 51 CUBOID AND NAVICULAR REACTIONS. (a) Cuboid rotates with eversion of calcaneus. Peroneal groove lost from view. (b) Navicular position influenced by talus Normal 75 per cent articulation reduced to 50 per cent.

though somewhat "dropped" because it is carried down with the lowered pitch of the calcaneus.

When the talus is visualized extending beyond the normal joint line, we infer that the navicular has made a similar advance. This could not take place unless the deltoid ligament had undergone elongation, which fault is a fundamental weakness of the structural composition of the foot.

The navicular does not demonstrate any articular space deviation in view of its normal acceptance of ball and socket movement. The navicular is forced to assume the downward direction that the talus takes due to the strong ligament integument restrictions. When the talus moves medially, the navicular keeps pace until restricted by the ligament integument. Then the talor head continues under the overburden of body weight until it reduces the normal percentage of the articulating surfaces to less than 75 per cent.

The navicular is subjected to exceptional stress when imbalance occurs. The effect of this on the bone shape will be discussed later It is interesting to note the tug of war in which the ligaments take part in an effort to prevent structural alteration One must also consider the excessive burden placed on the balancing muscles of the leg that undergird the navicular

Radiographic Features of Hindfoot and Mid–tarsal Fault (Figs. 52, 53).

Lateral View

(1) Altered mid–tarsal joint line with cyma broken
(2) Sinus tarsi, diminished, obliterated, or pseudo-sinus tarsi.
(3) Distal and plantigrade displacement of talus.
(4) Lowering of pitch of the calcaneus
(5) Lower arch height resulting from lower pitch of calcaneus
(6) Eversion of calcaneus
(7) Lateral tuberosity of calcaneus raised on higher plane.
(8) Sustentaculum tali lowered and defined as a broad area of density instead of a thin dense line
(9) Cuboid lowers and everts with calcaneal position
(10) Plantar tubercle of the cuboid fails to show peroneal groove due to rotation

Dorso-plantar View

(1) Mid-tarsal joint line altered with cyma broken.
(2) Head of talus loosely bound to anterior process of calcaneus. Gap at midfoot.
(3) Inferior calcaneo-navicular ligament elongated. Note distance from navicular to sustentaculum tali.
(4) Medial rotation of head of talus exceeds 15°.
(5) Less than 75 per cent of head of talus articulates with navicular.

COMPLICATIONS OF EXCEPTIONAL BONE SHAPES

In appraisal of hindfoot and mid-tarsal fault, the novice is likely to become confused if confronted by an exceptional bone shape, for this requires special consideration. Once these exceptional shapes are mastered, it is simple to appraise them in their true import.

Variations in embryonic development account for exceptional bone shapes. In an extensive study of this problem, Dwight emphasized the fact that tubercles of unusual size may frequently be attributed to the bony union of what otherwise might have been an occasional bone. At any event, we see a group of exceptional shapes affecting the calcaneus, talus, navicular, and cuboid with enough regularity to warrant their recognition as factors.

Harris and Beath have emphasized the importance of a strong shelf position of the sustentaculum tali. Inclinations of this process may predispose to mid-tarsal fault. Likewise, a diminutive anterior process of the calcaneus gives little support to the talus. These factors are quite obvious radiographically.

A short anterior process of the calcaneus in proportion to the rest of the bone and the talus could create a radiographic appearance of mid-tarsal fault because the talus extends so far beyond the calcaneo-cuboid joint line. A similar condition might occur in instances of an exceptionally long neck or head of the talus with an otherwise normally shaped anterior process of the talus (Fig. 54). The out-of-proportion size of the bone usually stands out as an exceptional bone-shape feature, but the surest way to differentiate it is to appraise all the factors of the syndrome for proof of fault. It is safe to assume that the problem is one of exceptional bone shape when the following is observed: the talus on a parallel plane, the sinus tarsi apparent, the calcaneus not everted, the talus not lowered in pitch and still closely bound to the anterior process of the calcaneus, and the only faulty factor a break in the normal mid-tarsal joint line due to the talus jutting forward.

In instances of a short-necked talus or of an exceptionally long anterior process of the calcaneus, a converse situation might occur in which all the features of the mid-tarsal fault syndrome might exist, except that the mid-tarsal joint line might appear quite normal. This would be caused by the neutralizing effect of the length of the bone contributing to the problem.

The navicular might have an enlarged tubercle that would appear to carry the talor head in a medial position; this pseudo fault is easily detected by assessing only the articular margins of the bones involved to check their true position. The cuboid has variable shapes, especially at the plantar aspect,

Figs. 52–53. Radiographic Features of Hindfoot and Mid-tarsal Fault

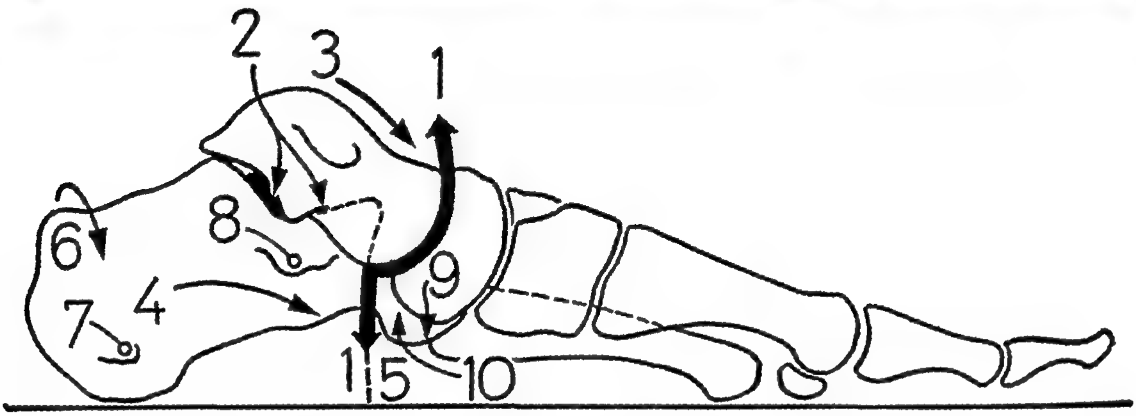


FIG. 52. LATERAL VIEW. (1) Altered mid-tarsal joint line with cyma broken (2) Sinus tarsi, diminished, obliterated, or pseudo sinus tarsi. (3) Distal and plantigrade displacement of talus (4) Lowering of pitch of the calcaneus (5) Lower arch height resulting from lower pitch of calcaneus (6) Eversion of calcaneus. (7) Lateral tuberosity of calcaneus raised on higher plane.(8) Sustentaculum tali lowered and defined as a broad area of density instead of a thin dense line. (9) Cuboid lowers and everts with calcaneal position (10) Plantar tubercle of the cuboid fails to show peroneal groove because of rotation.

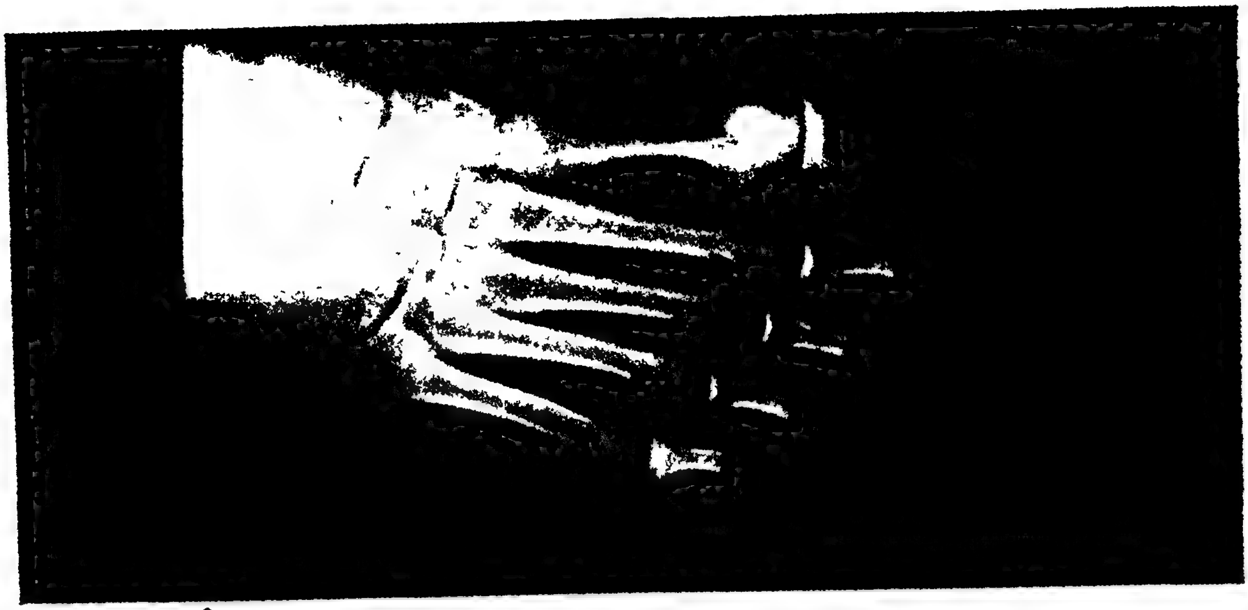
which sometimes has a hooklike tuberosity that undercuts the cuboid bone (Fig. 55). This exceptional shape should be quickly identified.

When only a single feature of a fault syndrome is present or unusual, consider the possibility of an exceptional bone shape.

Clinically, it is quite possible that the excessive span created by an exceptionally long neck of the talus might place an undue stress on the spring ligament, thereby predisposing the foot to fault. Exceptional bone shapes, as well as normal ones, are often noted in fault syndromes.

BONE SHAPES ALTERED BY FUNCTION

An entirely different variety of bone shapes is created by bone response to physical and physiological forces when subjected to unusual function. Wolff postulated this observation in a law that states: Every change in the form and function of the bones or of their function alone is followed by certain secondary



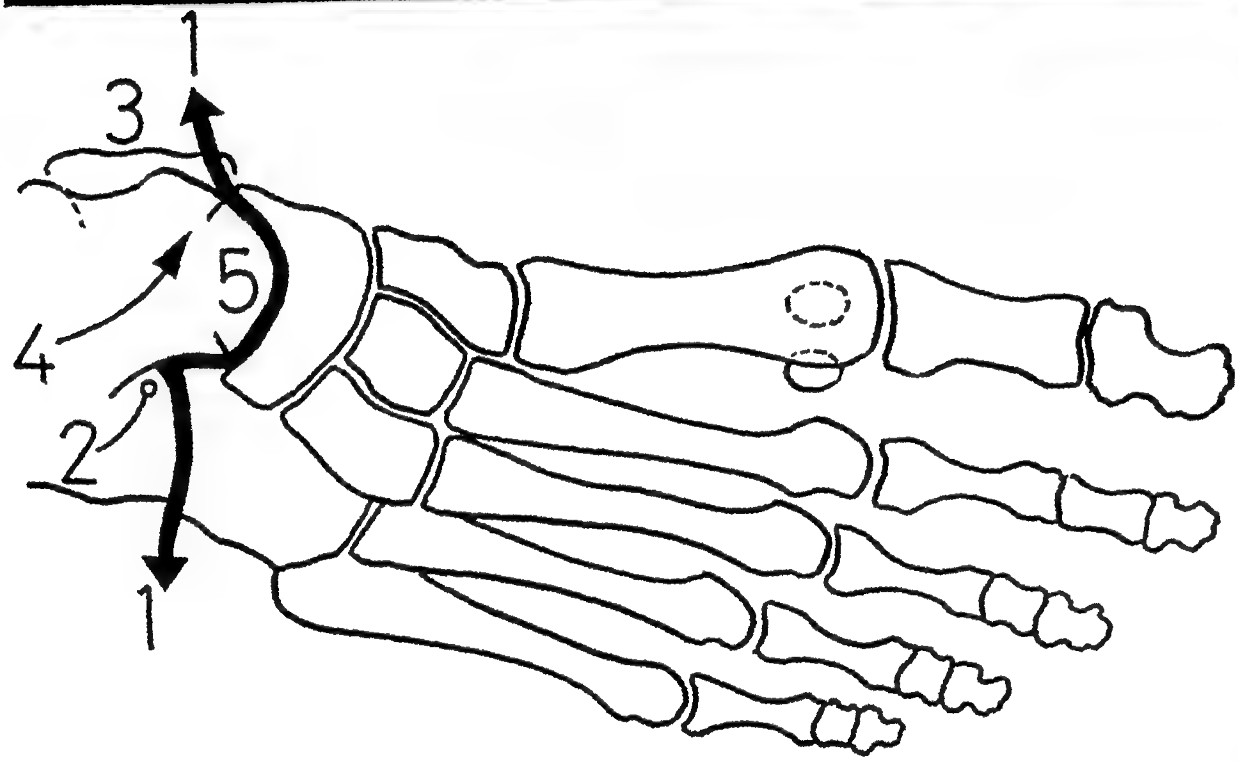


FIG 53. DORSO-PLANTAR VIEW. (1) Mid-tarsal joint line altered with cyma broken. (2) Head of talus loosely bound to anterior process of calcaneus. Gap at midfoot (3) Inferior calcaneo-navicular ligament elongated. Note distance from navicular to sustentaculum tali. (4) Medial rotation of head of talus exceeds 15° (5) Less than 75 per cent of talor head articulates with navicular.

alterations of their external conformation, in accordance with mathematical laws. The external contour represents mathematically simply the last curve uniting the ends of the various trajectories which make up the internal structure. Although several investigators have questioned the exactness of the mathematical aspects of this law, the general change in contour is indisputable. Extrinsic forces that act under Wolff's law include compression, tension, shear, bending, and torsion. When the foot undergoes structural change and the smooth function of transmitting physical forces through the foot in a normal manner

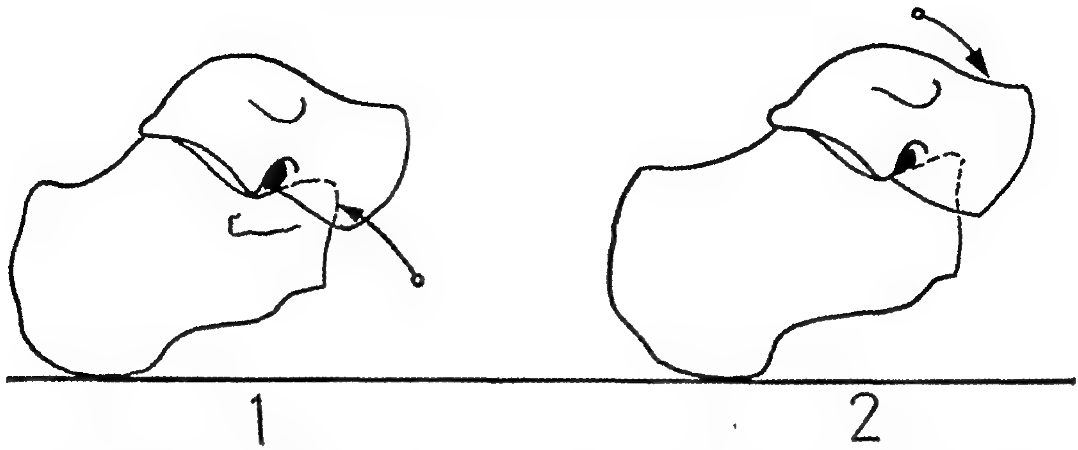


FIG. 54. PSEUDO MID-TARSAL FAULT RESULTING FROM EXCEPTIONAL BONE SHAPES. (1) Short anterior process of calcaneus (2) Long neck-shaped talus.

is altered, the stage is set for Wolff's law to work in changing bone shapes. The matter of time is then the all-important factor in determining the degree of alteration in bone shape that will be achieved. Although it is obvious that abuse of the foot in childhood is more likely to create altered bone shapes than abuse during adulthood, the law may prevail at any time. It is frequently asked whether bone shape may be reversed from faulty shape, when it is created by mal-functioning, to normal shape when function is improved. It is extremely doubtful that the physiological limits of the bone and of time would allow this recovery within a reasonable time. In childhood, a reversal could quite likely be instituted, provided prompt and efficient measures were taken early.

The physiological factors affecting bone maturation and continuing bone transformation must be reckoned with in considering altered bone shapes. Interference with an epiphysis may retard bone growth, as may the equalizing of leg length by surgical procedure. The fragility of demineralized bone is subject to pathological change in shape. Numerous other factors of this nature should be obvious to the apt clinician who first checks the radiograph for evidence of pathology before checking the patho-anatomy due to function alone.

The most common alterations that follow hindfoot and mid-tarsal fault affect four major bones. The calcaneus may exhibit condensation and in-

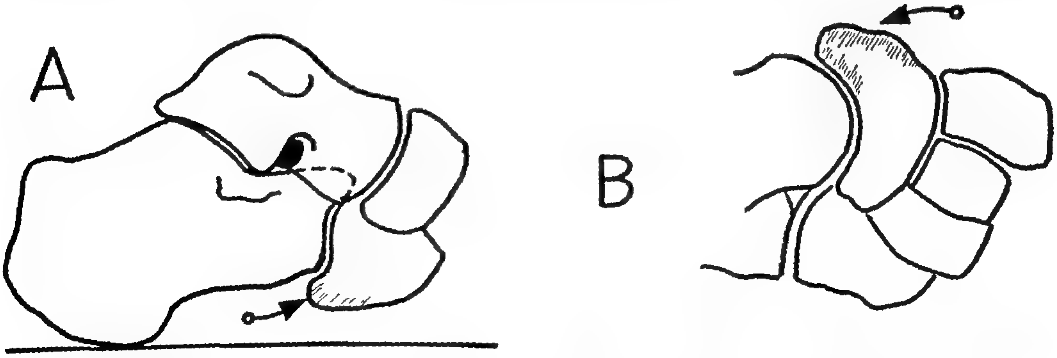


FIG 55. EXCEPTIONAL SHAPES OF NAVICULAR AND CUBOID BONES. (a) Extended plantar tuberosity of cuboid (b) Extended medial tuberosity of navicular.

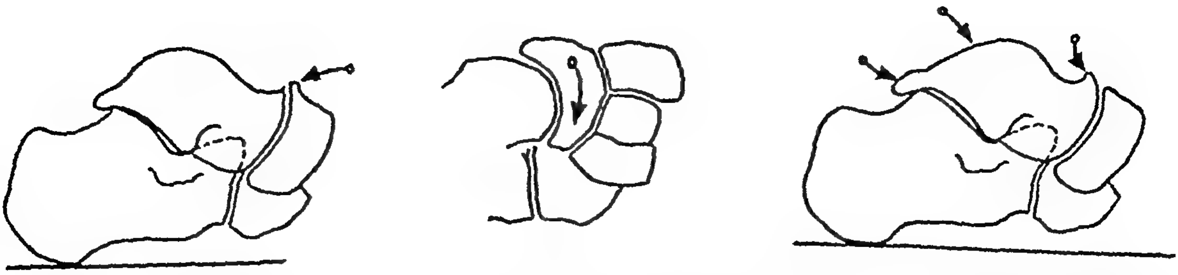


FIG 56. BONE SHAPES ALTERED BY FUNCTIONAL STRESSES. Eburnation at dorsal articulation margin of navicular. Wedge-shape compression of navicular. Talus receives compression forces that flatten its crown, stimulate extension of posterior tubercle, and create eburnation at dorsal articulation with navicular.

creased contour at the plantar aspect of the anterior portion of the bone if it has taken on a new function of weight support. Eburnation is frequently seen at the medial tuberosity of the calcaneus and when observed on an anatomical specimen is a ridge of bone rather than a spur-like spicule (Fig. 56). The talus, because of its mobile position, receives the greatest abuse; consequently, several changes are noted there. When the bone pivots forward to such an extent that the tibia must shift to the posterior aspect of the bone, the rounded crown becomes flattened. In these cases, the posterior tubercle of the talus becomes extended and enlarged, and the corresponding joint area on the calcaneus pushes upward in a thickened area. The head of the talus makes direct contact with the navicular, which is a vital point of weight-force junction. As the talus rotates medially, less compression is exerted on the medial side and more on the lateral side of the head of the bone; hence, a flattening and condensation occurs on the lateral side. This may extend dorsally as well. As a result of less strain, the medial aspect of the head is rounded in contour and loosely trabeculated. The navicular follows similar changes in contour. These are dramatically visualized in the dorso-planter view. The excess compression force creates a wedging of the bone shape on the lateral side and a loosely trabeculated, rounded contour on the medial border. At its dorsal aspect, as visualized in the lateral view, there is an extension of eburnation and condensation (Fig. 57). The cuboid seldom exhibits variation because it receives forces in a relatively even distribution compared to the unequal phases just described.

ESTIMATING THE DEGREE OF FAULT

The precise pattern in which a foot develops faults depends on several factors. Basically, the weakness of specific ligament groups under exceptional stress situations is responsible for any alteration of alignment. The ligament groups first affected may vary from one individual to another. Causes of this variation are related to the complete bony pattern of the foot in its structural stability or lack of stability. In other instances the various muscle groups that provide the secondary stabilizing factor may lack the strength to maintain proper foot balance, thereby abusing ligament integrity. Finally, the patient may assume a compensated foot posture to try to make up for the deficiency in strength and,

in so doing, may create a bizarre or atypical change in the development of the fault pattern.

Hindfoot and Mid-tarsal Fault. In this syndrome there are approximately fifteen features that may be recognized on the lateral and dorso-plantar radiographs. Some features are of major importance and others are subordinate. In practice, recognition of any major fault feature is sufficient evidence for diagnosis of the syndrome. This must, of course, be confirmed by elimination of any falsifying factors, such as exceptional bone shapes.

For practical purposes, four degrees of fault are graded:

Mild: only one major feature.
Medium: several major features.
Severe: severe mal-alignment of one or two major features with accompanying subordinate features.
Extreme: extreme mal-alignment of any one or combination of features.

In some instances, the talus may advance beyond the mid-tarsal joint line and fail to be displaced medially. This feature stands alone and may be con-

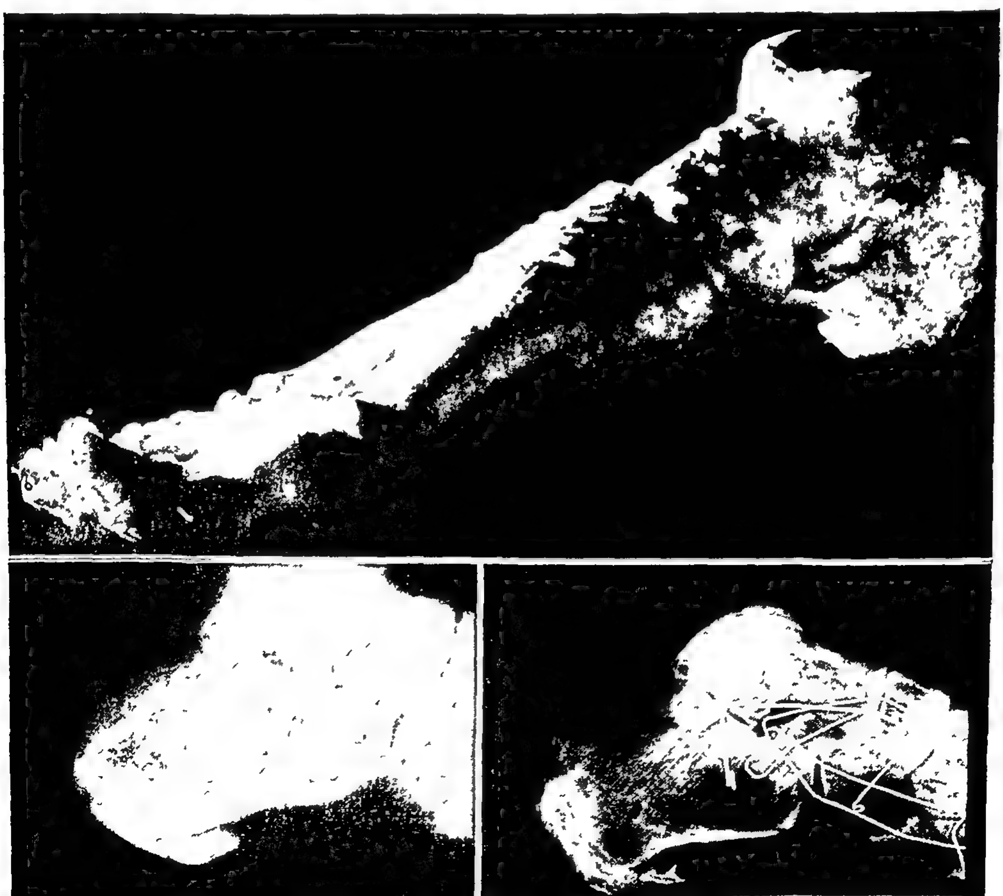


FIG 57. RADIOGRAPH OF CALCANEAL EXOSTOSIS SHOWS SPICULE Photograph of specimen with calcaneal exostosis demonstrates that it is an exostotic ridge bridging the medial and lateral tuberosities, rather than a localized "spur"

Figs. 58–69. Radiographic Study of Hindfoot and Mid-tarsal Fault Illustrates the fault syndrome in graduated degrees in various arch heights.

Figs. 58–61. Low Arch Foot-type

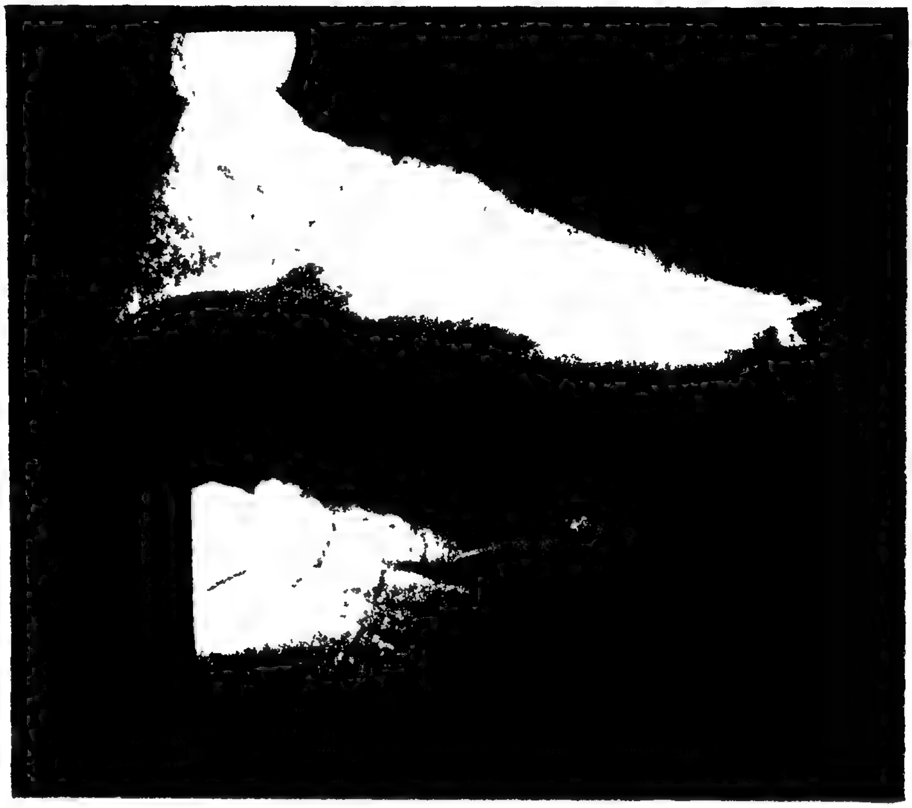


Fig. 58. Mild Degree Mid-tarsal Fault. *Lateral view.* Mid-tarsal joint line altered; slight distal and plantigrade displacement of talus. *Dorso-plantar view.* Mid-tarsal joint line slightly altered; mild medial rotation of talus.

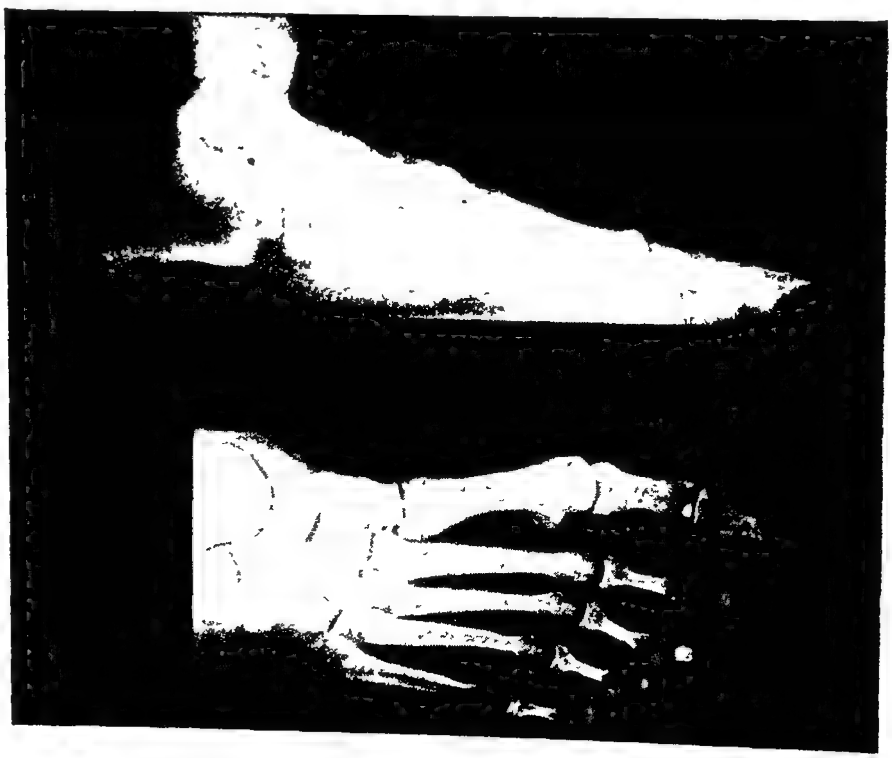


Fig. 59. Medium Degree Mid-tarsal Fault. *Lateral view.* Mid-tarsal joint line altered; distal advance of talus, exaggerated by short anterior process of calcaneus; eversion of calcaneus. *Dorso-plantar view.* Mid-tarsal joint line altered; distal advance of talus; head of talus loosely bound to calcaneus; medial rotation of talus with navicular holding its articulation.

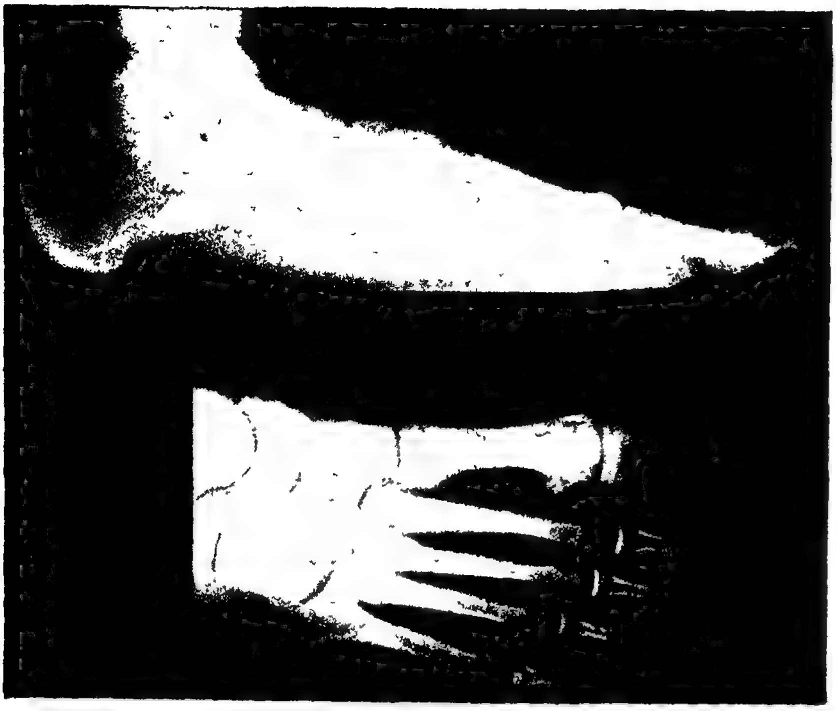


FIG. 60 SEVERE DEGREE MID-TARSAL FAULT. *Lateral view* Mid-tarsal joint line altered; distal advance of talus; plantigrade displacement slight; sustentaculum tali lowered; cuboid everted with calcaneus—no peroneal groove visible. *Dorso-plantar view.* Mid-tarsal joint line altered; medial rotation of talus. Only about 50 per cent of talus articulates with navicular.

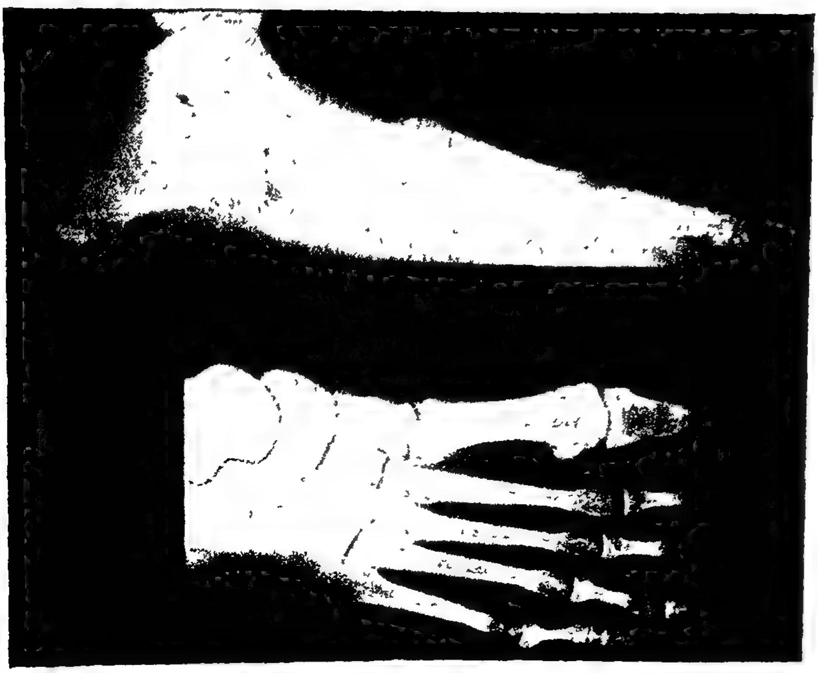
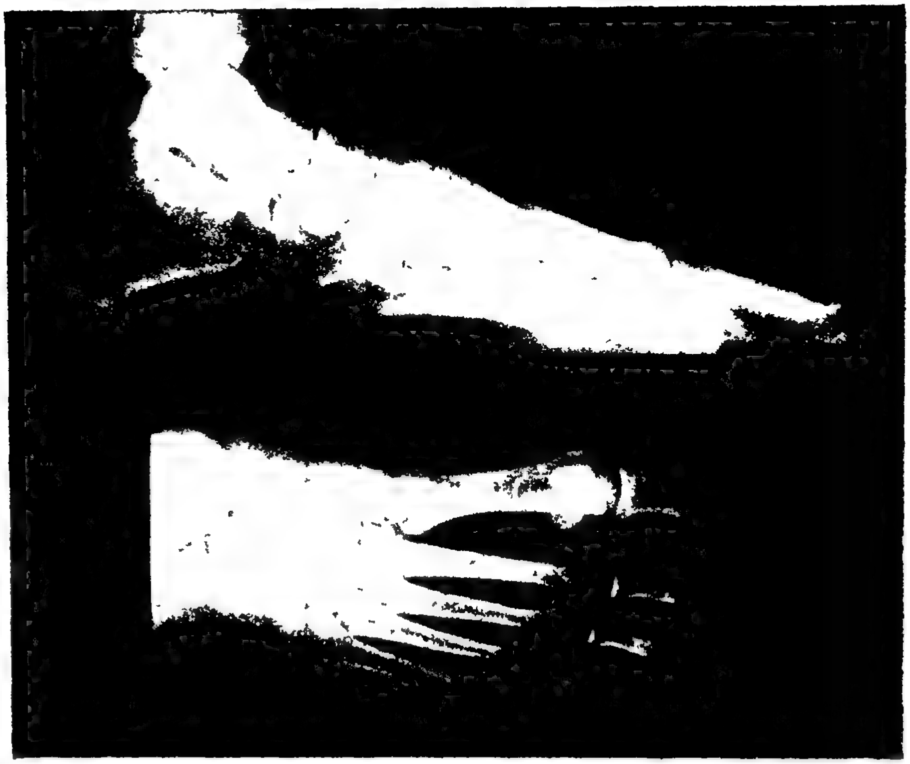


FIG. 61. EXTREME DEGREE MID-TARSAL FAULT. *Lateral view.* Mid-tarsal joint line altered; distal and plantigrade displacement of talus; sinus tarsi obliterated; pseudo sinus tarsi; sustentaculum tali lowered; calcaneus everted, crown of talus flattened; extension of posterior tubercle through functional stresses. *Dorso-plantar view* Mid-tarsal joint line altered; head of talus loosely bound to calcaneus; gap at midfoot, medial rotation of talus



Figs. 62–65. Medium Arch Foot-type

Fig. 62. Mild Degree Mid-tarsal Fault. *Lateral view*. Slight alteration of mid-tarsal joint; slight advance of talus. *Dorso-plantar view*. Alteration of mid-tarsal joint line; medial rotation of talus.

Fig. 63 Medium Degree Mid-tarsal Fault. *Lateral view*. Alteration of mid-tarsal joint line; advance of talus; plantigrade displacement of talus slight. *Dorso-plantar view* Mid-tarsal joint line altered, head of talus loosely bound to calcaneus; medial rotation of talus; navicular wedge-shaped

FIG. 64. SEVERE DEGREE MID-TARSAL FAULT. *Lateral view.* Mid-tarsal joint line altered; distal advance of talus; considerable plantigrade displacement of talus; sinus tarsi diminished. *Dorso-plantar view.* Mid-tarsal joint line altered; medial rotation of talus; about 50 per cent articulation of talus with navicular.

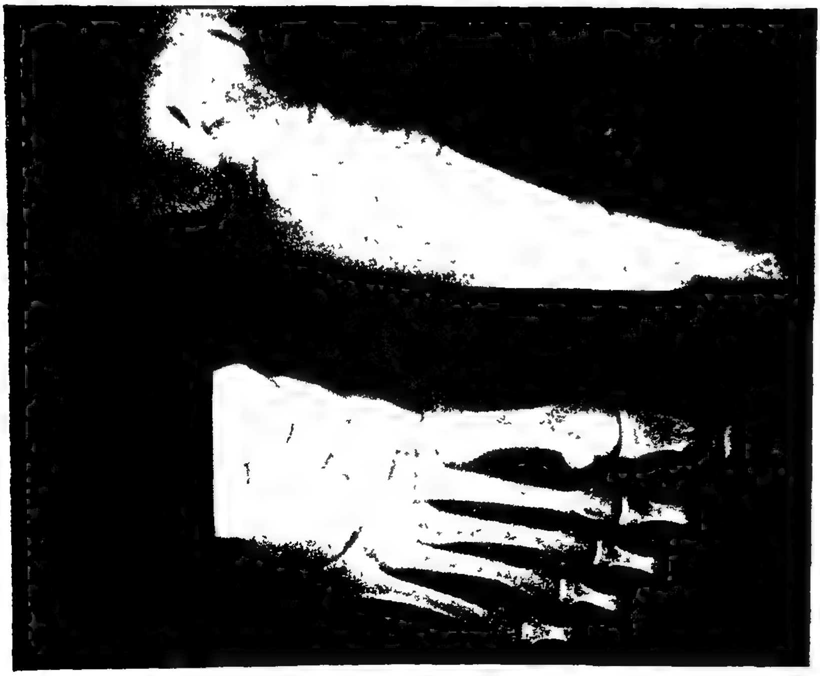


FIG. 65. EXTREME DEGREE MID-TARSAL FAULT. *Lateral view.* Mid-tarsal joint line altered; extreme distal advance of talus; plantigrade displacement of talus; sinus tarsi obliterated; pseudo sinus; eversion of calcaneus; lateral tuberosity on high plane; sustentaculum tali lowered. *Dorso-plantar view.* Mid-tarsal joint line altered; talus loosely bound to calcaneus; medial rotation of talus; navicular wedge-shaped.

Figs. 66–69. High Arch Foot-type

FIG. 66. MILD DEGREE MID-TARSAL FAULT. *Lateral view.* Mid-tarsal joint line altered; slight distal advance of talus. *Dorso-plantar view.* Minimal medial rotation of talus.

FIG. 67. MEDIUM DEGREE MID-TARSAL FAULT. *Lateral view.* Mid-tarsal joint line altered; distal advance of talus; plantigrade displacement of talus. *Dorso-plantar view.* Mid-tarsal joint line altered; medial rotation of talus.

FIG. 68. SEVERE DEGREE MID-TARSAL FAULT *Lateral view* Mid-tarsal joint line altered; distal advance of talus; calcaneus everted, lateral tuberosity raised; sustentaculum tali lowered. *Dorso-plantar view.* Mid-tarsal joint line altered; medial rotation of talus; prominent tuberosity of navicular.

FIG 69 EXTREME DEGREE MI TARSAL FAULT. *Lateral view.* Mid tarsal joint line altered, dista advance of talus, plantigrade dis placement of talus; sinus tars diminished; calcaneus everted *Dorso-plantar view* Mid-tarsa joint line altered; medial rotatio of talus, navicular shows compres sion wedge-shape change.

sidered of mild degree unless it should be accentuated enough to classify it in the extreme degree. In other instances, medial rotation of the talus is predominant, with very little forward displacement. Consequently, this would be classified as mild in degree, unless extremely rotated. Any one of the entire gamut of features may predominate in certain feet. The varying degrees of change emphasize the individuality of each case and its subsequent radiographic interpretation (Figs. 58–69).

Degree of Fault Related to Arch Height. From a purely mechanical standpoint, the highly arched foot is less likely to develop mechanical fault because the weight forces are likely to follow a course through the posterior subtalor joint to the contact area, rather than try to move the center of gravity forward through the foot. The truss-like support of the plantar fascia and intrinsic muscles is easier to achieve in the highly arched foot.

In the case of medium arch height, the center of gravity is more likely to be carried through the anterior portion of the subtalor articulation, thereby tilting the entire hindfoot and mid-tarsal relationship out of balance. In this type of arch, the long span of the fascia along the plantar aspect is not so effective in trussing the structural arrangement together as is that of the highly arched type

In low-arched feet, there is small limit for lowering of the pitch of the calcaneus and the attendant changes; nevertheless, this foot type is very vulnerable because gravity forces are predominantly active in jarring every articulation.

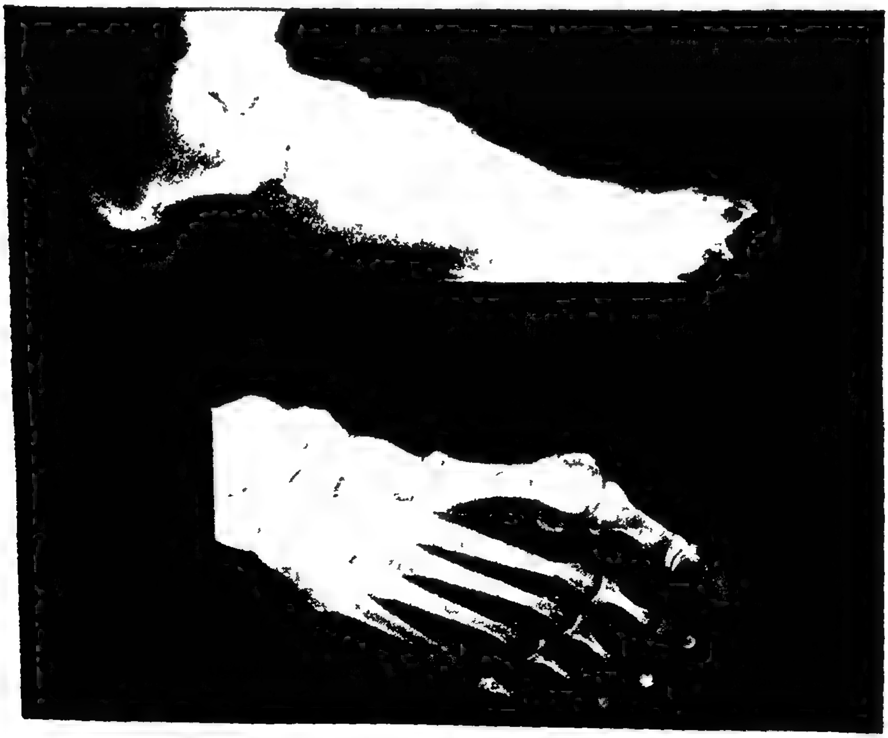


FIG 70. MID-TARSAL FAULT—HALLUX VALGUS

Likewise, the plantar fascia and other investitures are subject to abuse and are not mechanically situated in a position to be of much value in maintaining good foot balance.

It may be understood that the degree of fault is related to arch height and that the arch of medium height is more likely to develop a greater degree of fault.

EXTRANEOUS FACTORS ASSOCIATED WITH MID-TARSAL FAULT

Any number of miscellaneous problems affecting the feet may occur as an associated factor in mid-tarsal fault. The entire gamut of metatarsal and orthodigital lesions may accompany mid-tarsal fault. A few of these deserve special mention. Hallux valgus is a deformity that may be frequently visualized (Fig. 70). In the past, speculation was strongly in favor of suspecting a depression of the longitudinal arches in every case of hallux valgus, but there does not seem to be any basis of fact in this assumption because many radiographs confirm hallux valgus in normal, highly arched feet There is a definite tendency for the creation of hallux valgus when the foot elongates in the process of acquiring mid-tarsal fault and when footgear does not accommodate the newly lengthened foot.

Morton's syndrome (a syndrome related to atavism of the first metatarsal segment) is not necessarily found in cases of mid-tarsal fault, although Morton theorizes his syndrome as the primary cause of foot disorder (Fig. 71). In

Fig 71. Mid-tarsal Fault—Morton's Syndrome

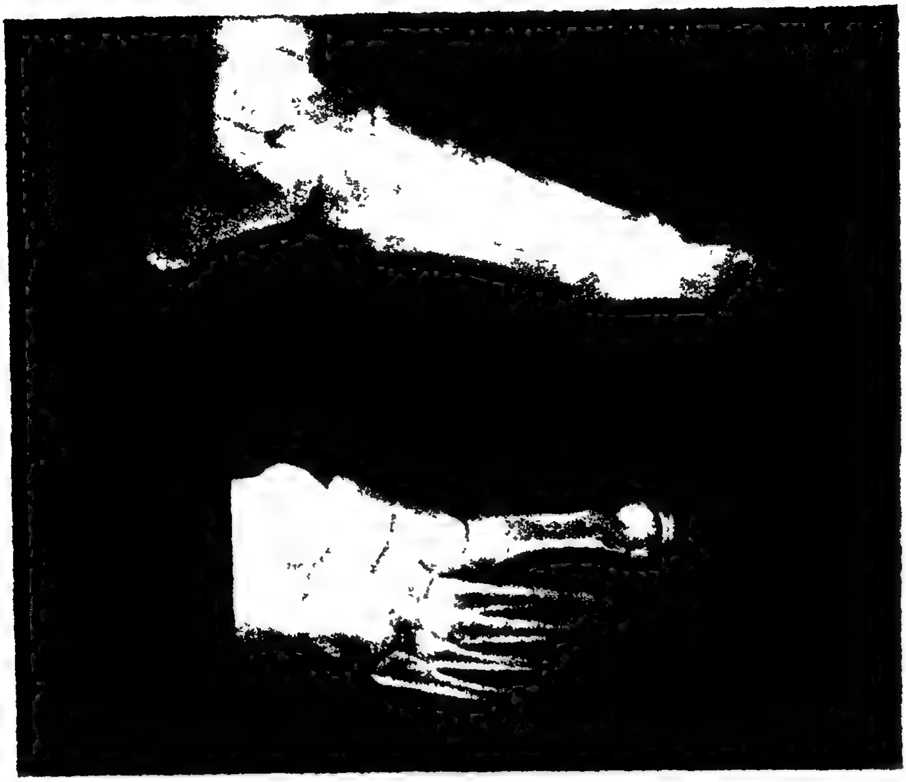


FIG. 72. MID-TARSAL FAULT—CONVERSE OF MORTON'S SYNDROME (LONG FIRST METATARSAL)

many feet exhibiting fault the relative length of the first metatarsal is longer than that of the second metatarsal. This may be due to the medial arch segment's being forced forward to create a pseudo lengthening of the first metatarsal. On the other hand, comparison of the unit length of the first metatarsal of one foot with the unit length of the second metatarsal of the same foot has disclosed a long first metatarsal in many instances of mid-tarsal fault (Fig. 72).

An excessively large os trigonum has been a subject of attention to Interland, who felt that it was an indication of exceptional stress in the area. This writer believes that the posterior tubercle of the talus undergoes various alterations because of its altered function in receiving stresses when the talus assumes mal-position in mid-tarsal fault (Fig. 73). In some instances the posterior tubercle is flattened and ridgelike; in other cases a portion of the ridge seems to be fragmented from the body of the bone This feature should be distinguished from the recognized supernumerary bone, the true os trigonum.

FUNCTIONAL FOOT CONDITIONS

There are cases in which an individual indulges in faulty foot posture or in faulty gait through habit and the freedom allowed by joint movement. These problems are recognized clinically and produce a number of clinical symptoms, but the radiographic study does not demonstrate any osseous patho-anatomy.

COMPENSATIONS FOR MID-TARSAL FAULT BY FOREFOOT ADDUCTION

There is a well-known tendency for the young child to attempt to establish balance and equilibrium by adducting the forefoot when the foot has mid-tarsal fault. If maintained, this attitude of the foot serves to create a struc-

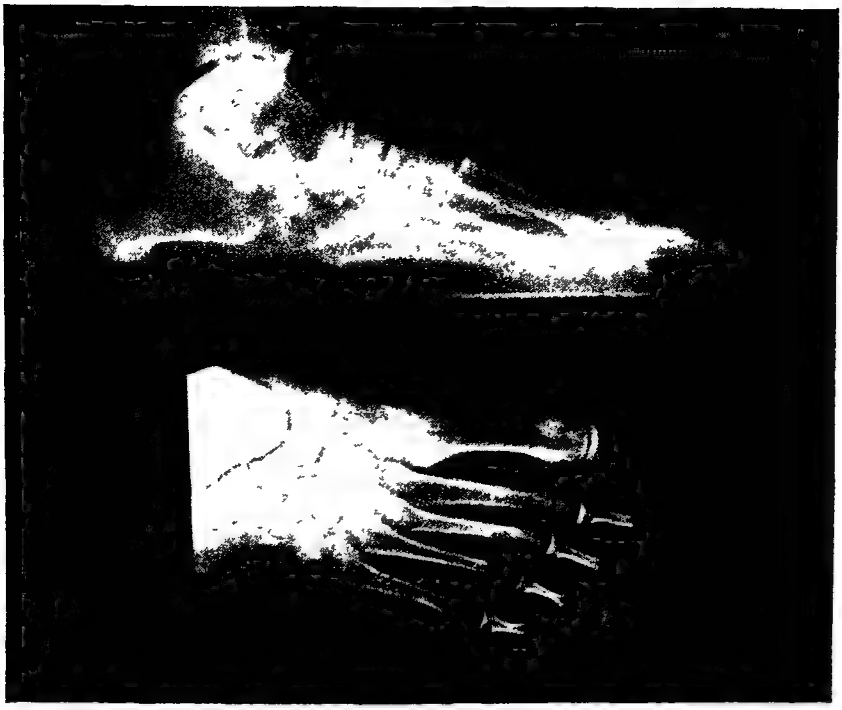


FIG 73 MID-TARSAL FAULT—EXTENSION OF POSTERIOR TUBERCLE OF TALUS

tural pattern in the adult foot that is somewhat atypical in regard to the forefoot features following mid-tarsal fault. The principal change relates to a severe varus of all the metatarsals except the fifth and a corresponding varus of the toes The cuneiforms are not much affected by this extreme varus, although the medial cuneiform may not exhibit medial rotation on its long axis (Fig 74).

The dorso-plantar view demonstrates all the features of forefoot compensation.

Clinical Considerations of Hindfoot and Mid-tarsal Fault

(1) The best method of analyzing a faulty foot is by comparison of the radiograph of the faulty foot with that of a normal foot.

(2) A very helpful means of confirming the degree of fault in each foot is by a comparative study of both feet

(3) An attempt to estimate original arch height should be made in order to establish the chronicity of the present condition

(4) The arch height of the involved foot may be a clue to the degree of fault Since the medium arch height is more likely to develop fault, both high and low arch heights exhibit less change

(5) A means of classification is by recognition of the four degrees of fault: mild, medium, severe, and extreme The assessment of these degrees has been illustrated in the preceding pages

(6) Little initial alignment change is necessary to elicit painful symptoms.

(7) In evaluating both feet, when one exhibits more fault than the other, it is well to realize that the foot exhibiting the greater fault may quite likely have less pain. This is true because of a pattern of chronicity. One foot origi-

FIG. 74. MID-TARSAL FAULT—COMPENSATED BY FOREFOOT ADDUCTION

nally develops structural fault with attendant pain and the individual ignores the condition or favors the painful foot by transferring the burden to the other foot. Eventually, the foot that now receives the greater load breaks down and is more acutely painful than the other foot, which by this time has reached some degree of quiescence. This is particularly true in cases of long duration.

(8) Elongation of the foot is in proportion to alteration of the mid-tarsal joint line by forward projection of the talus. Elongation is not necessarily an index of the severity of the fault because some of the forward advance of the bone column may be absorbed by buckling at several joints, most particularly medial rotation of the talus.

(9) Bone shapes altered by function always indicate chronicity of the fault and poor prognosis.

(10) Exceptional bones may mean more than a confusing factor of interpretation They can also create exceptional stress conditions.

(11) Correlate each radiographic finding with the clinical history of the case wherever possible. Relate areas of pain to their anatomical counterpart on the radiograph.

(12) Utilize the radiographic findings to develop a comprehensive diagnosis of the case, an intelligent prognosis, and a practical treatment plan.

(13) Present the radiographic findings to the patient only by discussing the salient features that have practical significance A normal study may be used for comparison.

(14) In gauging prognosis, remember that ligamentous tissue cannot reassume its original size and shape Any mid-tarsal line break of more than 4 mm. will be difficult to restore to normal. Intrinsic foot muscles must take over the

work of weakened ligaments to restore alignment, and must be aided by perfectly balanced leg muscles. If more than a 4 mm. break is established, an appliance will probably be needed to restore a useful foot.

(15) Treatment should be directed toward restoration of the foot by every indicated form of rehabilitation procedure, as in the following: physiotherapeutic heat to allay inflammation, hydrotherapy to massage weak intrinsic muscles and to increase the conductivity of the skin, low-voltage electrical stimulation to renew and strengthen muscle response to stimuli, foot exercise routines and gait training, adhesive taping to draw the foot gradually into an improved alignment and to rest the abused ligaments and other soft-tissue structures that maintain the integrity under normal circumstances, use of accommodative appliances when faulty bone shape precludes normal rehabilitation of foot shape, use of balanced inlays to restore a normal foot alignment by balanced gait, and use of the Whitman foot brace to gain specific control of the calcaneus in restoring the basis for foot improvement. After considering the radiographic features with specific planning for rehabilitation, the proper treatment may be selected.

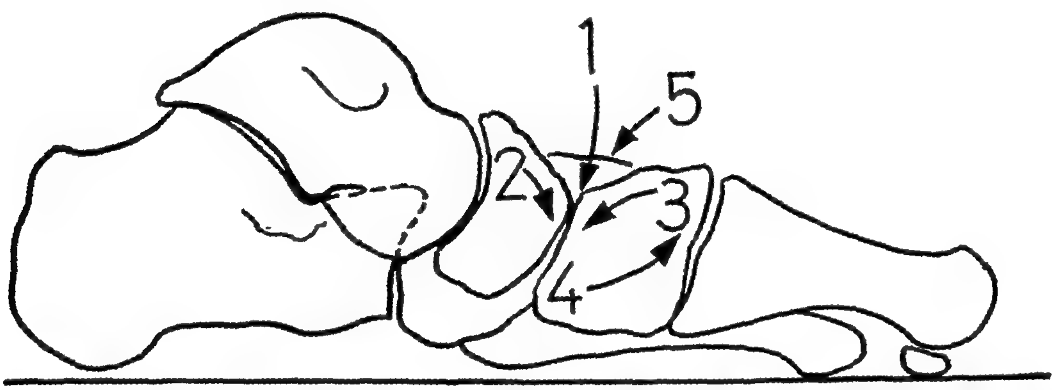


FIG 75 RADIOGRAPHIC FEATURES OF NAVICULAR-CUNEIFORM FAULT. *Lateral view.* (1) Depression of navicular-cuneiform joint (2) Navicular pivoted downward at anterior border. (3) Medial cuneiform pivoted downward at posterior border. (4) Anterior border of medial cuneiform pivoted upward, throwing the first metatarsal base into prominence. (5) In extreme cases, middle cuneiform is visualized as an inverted triangle rising above the articulation.

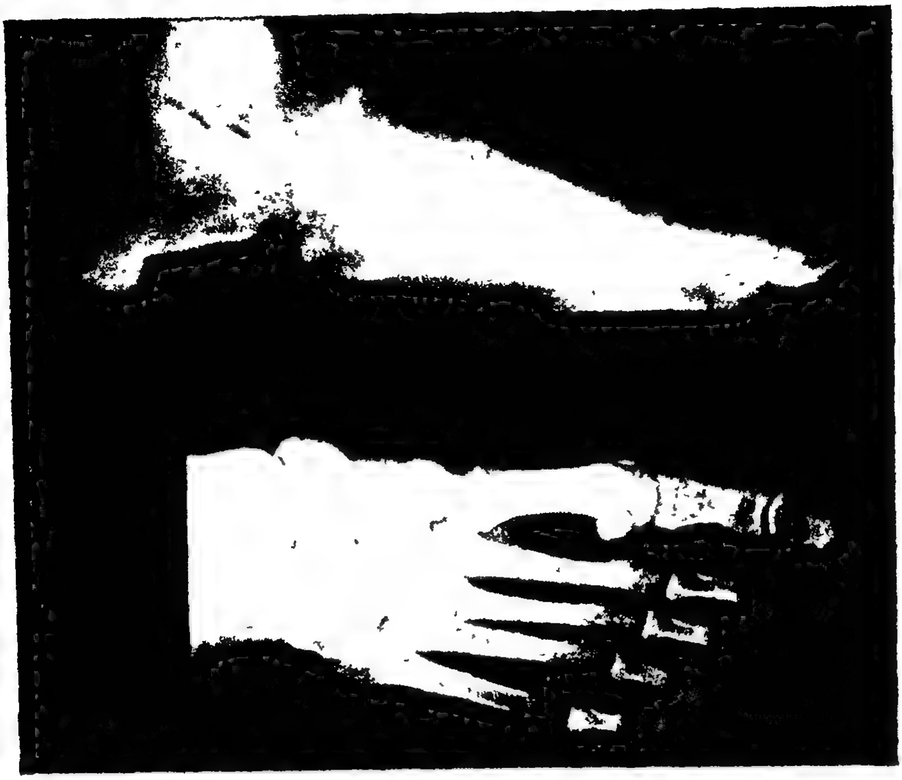


FIG. 76. NAVICULAR-CUNEIFORM FAULT—MILD DEGREE. Slight depression of navicular-cuneiform joint. Note slight dorsal prominence of base of first metatarsal bone.

(16) Altered bone shape is a factor that calls for a guarded prognosis. This is because of the fact that accommodation to faulty bone shape usually transpires over a lifetime, even though the patient may experience dramatic relief from a small measure of rehabilitation Reshaping of the foot is scarcely possible, but accommodative procedures and appliances are indicated.

(17) Be cognizant of the fact that a return to improved foot status may incite the same painful symptoms that occurred when the foot became faulty. Dye has termed this "reaction."

(18) Since the restoration of good alignment is limited in proportion to the extent of ligament damage and the shape of bones, do not expect to demonstrate dramatic improvement in structural alignment in a series of radiographs following treatment.

(19) Do expect to demonstrate the improved alignment by radiographing the foot when properly balanced by an appliance within the shoe

(20) Proof of the effect of taping rehabilitation may be demonstrated by applying a strongly applied taping and performing a radiograph to compare with the foot as originally radiographed

NAVICULAR-CUNEIFORM FAULT

The profound structural changes that originate from hindfoot and mid-tarsal fault are extended to the tarsal region through two pathways navicular-cuneiform fault with involvement of the medial arch segment and calcaneo-cuboid fault with involvement of the lateral arch segment. The transverse tarsal arch is necessarily affected.

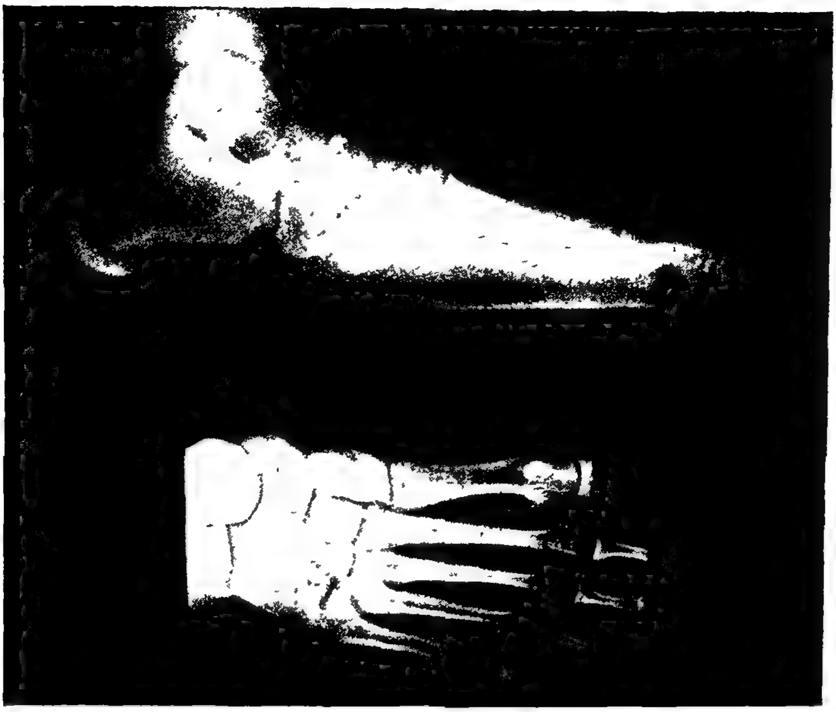


FIG. 77 NAVICULAR-CUNEIFORM FAULT—MEDIUM DEGREE Marked depression of navicular-cuneiform joint Lowering of forefoot arch segment Hypermobility gap between medial and middle cuneiforms

Although navicular-cuneiform fault is a sequel to mid-tarsal fault, it may represent a basic weakness of the foot and be the only radiographic evidence of foot fault This occurs, usually, in long feet with a maximum stress imposed upon the cuneiform-navicular articulation. Weakness of the tibialis anticus muscle or a variation of its insertion may also contribute.

Radiographic Impressions

The lateral radiographic view presents several features characteristic of the navicular-cuneiform fault syndrome Instead of the evenly aligned dorsal articulations found in the normal foot, there is a sagging depression at the navicular-cuneiform articulation This is created by the navicular pivoting downward at its anterior margin as it follows the direction presented by the talus The cuneiforms pivot downward at their posterior margin, which is adjacent to the navicular, thereby creating the depression of the articulation The articular space of the joint is closed at the dorsum and open at the plantar aspect to indicate the changed position of the bones Because the medial cuneiform pronates with the downward thrust of the talus, the middle cuneiform is usually visualized from the lateral aspect as an inverted triangle rising above the articulation. The anterior and superior aspect of the medial cuneiform pivots upward with the base of the first metatarsal and creates the prominence that is such a frequent clinical finding, on the dorsum of the foot (Figs. 75–79)

FIG 78 NAVICULAR-CUNEIFORM FAULT—SEVERE DEGREE Secondary to mid-tarsal fault; depression of navicular-cuneiform joint; lowering of forefoot arch segment; hypermobility gap between medial cuneiform and base of second metatarsal.

Lateral View

(1) Depression of navicular–cuneiform joint
(2) Navicular pivoted downward at anterior border.
(3) Medial cuneiform pivoted downward at posterior border.
(4) Anterior border of medial cuneiform pivoted upward, first metatarsal forced into dorsal prominence.

Involvement of the Medial Arch Segment. The predominant pattern of change of the medial arch segment under the duress of foot imbalance will be described first. It is chiefly appraised from the dorso-plantar view. Both mid-tarsal and navicular-cuneiform faults may be contributory.

As the talor head pushes the navicular forward and medially, a buckling reaction takes place due to the counterforces from the weight-supporting contact flowing back through the first, second, and third metatarsal bones

The following is the radiographic visualization. the medial cuneiform rotates on its long axis into pronation and, instead of following its parallel course with the axis of balance, tends to buckle at its lateral articulation with the base of the first metatarsal. This presents a zigzag line from talus, to navicular-cuneiform, to metatarsal In pronating, the medial cuneiform opens a gap with the middle cuneiform and the base of the second metatarsal. This has been described clinically by Morton as "hypermobility." In severe cases of pronation the gap is closed from a radiographic viewpoint because the inferior aspect of the joint is closed and the superior aspect opened. The first metatarsal rotates in a pronated direction with the medial cuneiform.

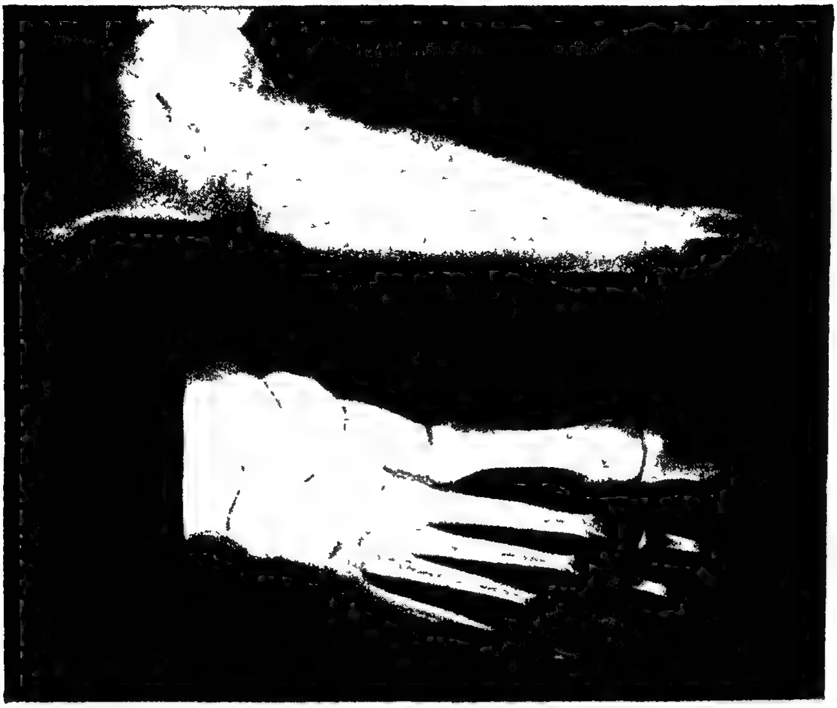


FIG 79. NAVICULAR-CUNEIFORM FAULT—EXTREME DEGREE. Secondary to mid-tarsal fault; depression of navicular-cuneiform joint; middle cuneiform rises above the joint line as an inverted triangle, hypermobility of segment between medial cuneiform and base of first metatarsal.

The second cuneiform, by virtue of being placed in a more dorsal position, is better visualized, as is more of the base of the second metatarsal. Medial movement of the navicular tends to move the middle cuneiform on its long axis slightly counter-clockwise This helps to accentuate the gap with the medial cuneiform

The lateral cuneiform exhibits the greatest torsion, as is demonstrated by its articulating member, the third metatarsal, which lies on a varus slant because of the twisting of the cuneiform. The *third toe* deviates in a valgus position when this mal-alignment exists. This is observed clinically many times when the patient stands and the second and third toes separate (Fig. 80).

Involvement of the Transverse Arch Depression of the navicular with pronation and spreading of the transverse arch is responsible to a large degree for the hypermobility of these segments which is observed as a laxity on palpation of the segment A loss of the strong power of the peroneus longus also contributes to this laxity. The altered position of the bones in the entire fault sequence places the muscles at a mechanical disadvantage in obtaining the proper leverage and pulling which is normally intended.

In addition to the problem of instability, the relation of the medial arch segment to the lateral arch segment, through articular position, adds to the complexity.

In long-standing problems in which wedging in the shape of the navicular has occurred, all the changes are accentuated. In moderate cases some of these

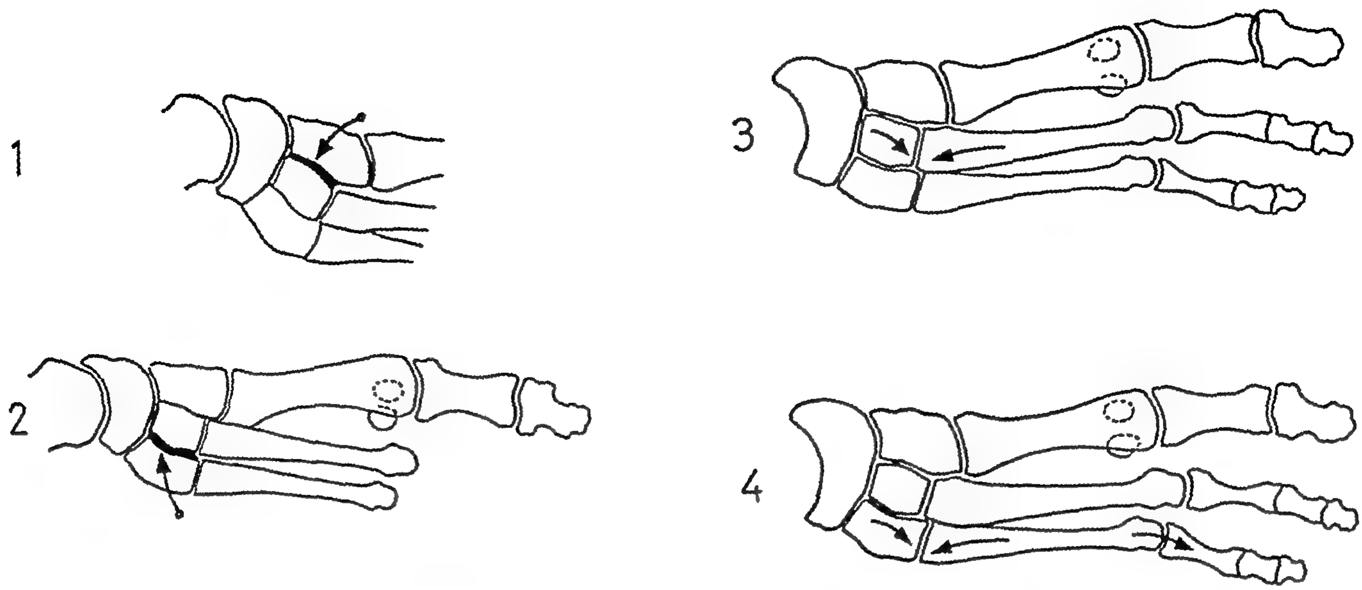


Fig. 80. Radiographic Features of Involvement of Medial Arch Segment. *Dorso-plantar view.* (1) A gap is visualized between the base of the medial cuneiform and the base of the second metatarsal in mild to medium rotation of the medial cuneiform. The gap is closed in severe and extreme cases (2) A gap between the middle and lateral cuneiforms is visualized when the transverse arch is flattened by depression of the navicular and cuneiforms. (3) Torsion of the middle cuneiform carries the second metatarsal into mild varus. (4) Torsion of the lateral cuneiform carries the third metatarsal into greater varus with the third toe buckling into valgus.

Refer to: Figs. 58, 59, 63, 64, 72, 73, 74.

alterations are minimal on radiographic examination. Extreme disorganization is possible in severe cases (Figs. 81, 82).

Radiographic Features of Medial Arch Involvement

Dorso-plantar View

(1) Gap between bases of medial cuneiform and second metatarsal in mild to medium rotation of cuneiform. Gap closed in severe to extreme cases.
(2) Gap between middle and lateral cuneiforms in transverse arch depression.
(3) Torsion of middle cuneiform carries second metatarsal into mild varus.
(4) Torsion of lateral cuneiform carries third metatarsal into varus with third toe buckling into valgus.

Clinical Considerations

Long thin feet frequently produce navicular-cuneiform fault due to the excessive stresses that develop in the long arch span. This fault is in the type of foot that may be benefited by a typical Shaeffer-type, longitudinal arch appliance because the supportive feature undergirds the navicular-cuneiform joint.

When secondary changes of the medial arch segment have developed, extensive rehabilitation with adhesive dressings, and appropriate physiotherapeutic measures are indicated.

It is a mistake to use a calcaneal control-type of appliance on this foot type unless the navicular-cuneiform fault is secondary to mid-tarsal fault. If this is the case, the hindfoot must be realigned.

FIG 81. NORMAL HINDFOOT AND MID-TARSAL JOINT. Medium inversion with varus slant of second and third metatarsal shafts Buckling of third toe. Slight hypermobility of first cuneiform and second cuneiform bones.

FIG 82 SAME CASE AS FIG 81—FIVE YEARS LATER Mid-tarsal fault Navicular-cuneiform fault Complete disorganization of transverse tarsal arch and medial and lateral arch segments (Courtesy of Dr. R Oestreich)

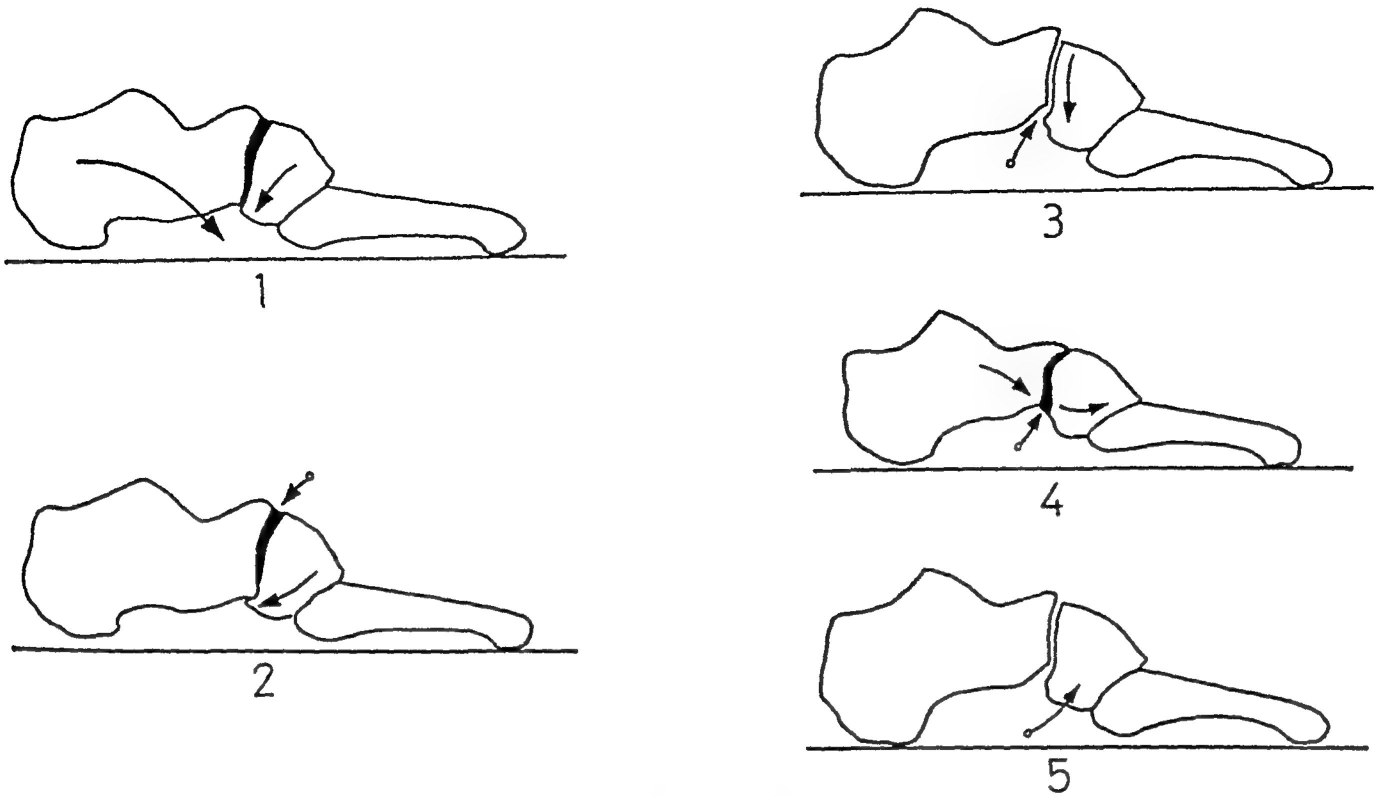


Fig. 83. Radiographic Features of Calcaneo-cuboid Fault. *Lateral view.* (1) Cuboid is forced downward with change in pitch of calcaneus. (2) Cuboid sometimes moves under anterior process of calcaneus. (3) Rarely, cuboid drops with articular space even, but articulating margin is lowered at its plantar aspect. (4) Sometimes dorsal aspect of joint is closed and plantar aspect is open because of weakness of calcaneo-cuboid ligaments. (5) Peroneal groove is poorly defined when cuboid is rotated on its long axis.

CALCANEO-CUBOID FAULT

Continuation of mal-alignment as a result of altered position of the calcaneus is visualized as it further involves the calcaneo-cuboid articulation and the outer-arch segment. Instances occur, usually in highly arched feet, where the fault is found specifically. Various clinicians have drawn a great deal of attention to a condition designated as "dropped cuboid." Actually, a specific downward displacement of the cuboid is a rarity; rather, the altered position, consisting more of a rotation of the cuboid on its long axis, represents the true cuboid lesion. The individual integrity of the various ligament bands that hold the cuboid in close articulation determine to a great degree just how the bone will behave under stress, consequently, we have several minimal types of fault.

Radiographic Impressions

As the calcaneus lowers in pitch, the lateral radiograph reveals the cuboid forced downward. At the same time, the cuboid undergoes a rotation on its long axis and the plantar tubercle (which normally is accentuated as added radiographic density by the groove for the peroneus longus) loses this sharp delineation as the cuboid everts The twisting stress that develops around the calcaneo-cuboid joint, coupled with the breaking stress as it is forced downward, may open the dorsal aspect of the joint and close the plantar one. The cuboid seems to attempt to move under the anterior process of the calcaneus (Figs. 83–86).

Fig. 84. Calcaneo-cuboid Fault—Dropped Cuboid

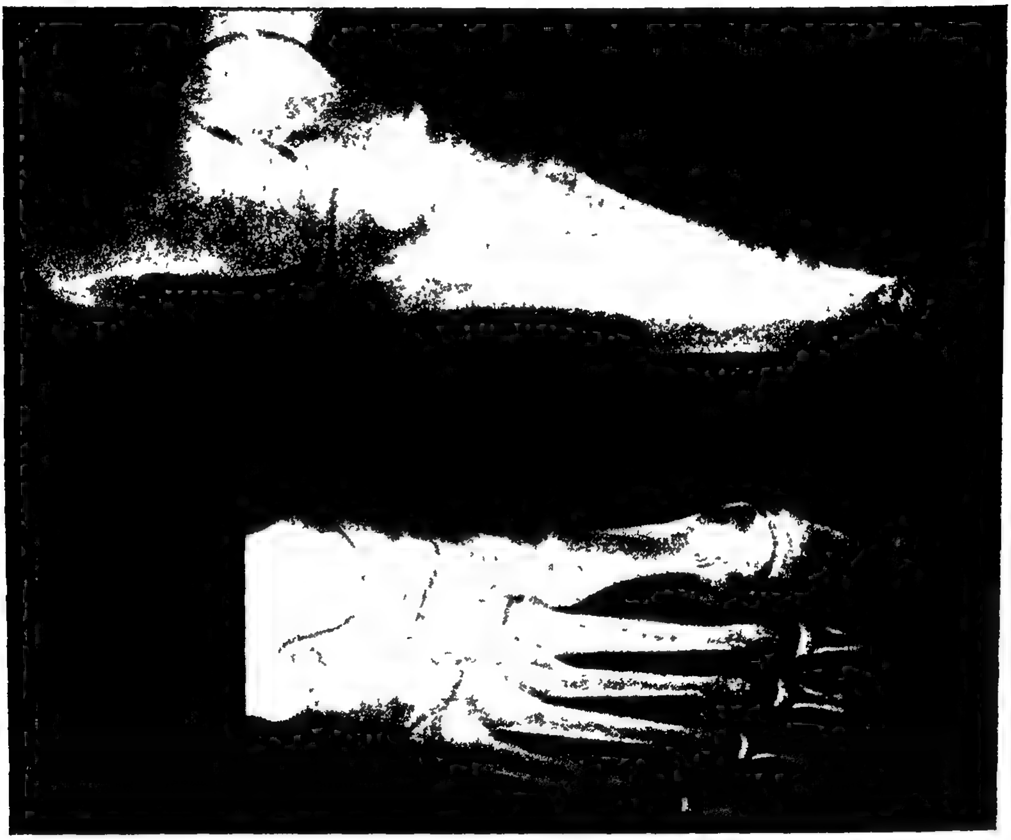


Fig 85. Calcaneo-cuboid Fault—Secondary to Mid-tarsal Fault. Gap at dorsal aspect; plantar aspect closed.

Fig 86 Calcaneo-cuboid Fault—Cuboid under Anterior Process of Calcaneus

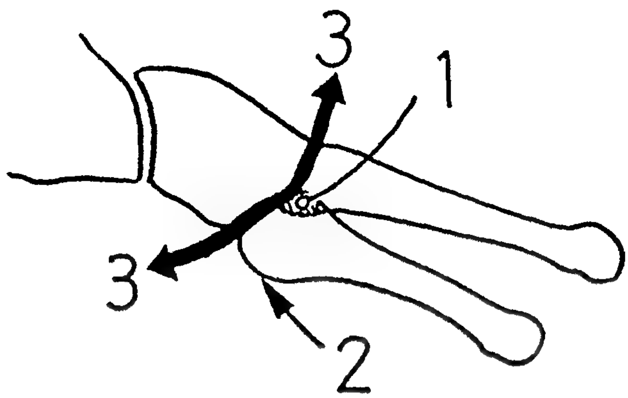


Fig 87. Radiographic Features of Involvement of Lateral Arch Segment. *Dorso-plantar view.* (1) Fourth metatarsal base overlaps fifth less than 50 per cent (2) Base of fifth metatarsal appears broadened due to rotation. (3) Increased joint space between fourth and fifth metatarsals with cuboid creates hypermobility and laxness.

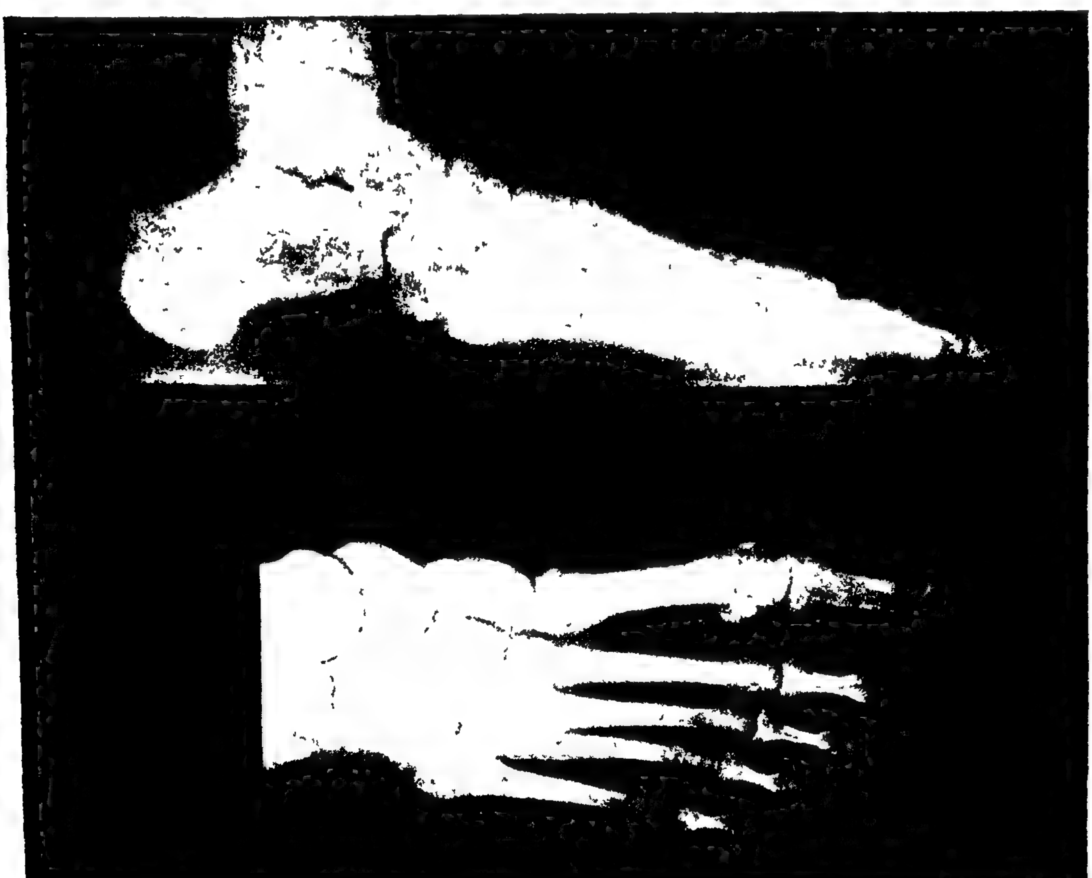


Fig 88 Calcaneo-cuboid Fault with Lateral Arch Involvement Cuboid lowered and everted, gap at base of fourth metatarsal as it articulates with fifth metatarsal, broadening of base of fifth metatarsal due to rotation.

Radiographic Features of Calcaneo–cuboid Fault

Lateral View

(1) Cuboid forced downward with lowering in pitch of calcaneus.
(2) Cuboid sometimes moves under anterior process of calcaneus.
(3) Rarely cuboid drops with articular margin, lowered calcaneal joint
(4) Dorsal aspect of calcaneo–cuboid joint sometimes gaps.
(5) Peroneal groove poorly defined when cuboid is rotated on long axis.

Involvement of Lateral Arch Segment. The dorso-plantar view demonstrates in a very definite manner the effect of the rotation of the cuboid which alters the position of the bases of the fourth and fifth metatarsal bones that constitute the lateral-arch segment Whereas the fourth metatarsal overlaps the fifth metatarsal base by approximately 50 per cent in the normal foot, calcaneo-cuboid fault reduces the overlap to as little as 10 per cent The fifth metatarsal rotates on its long axis so that its base is broadened and the obliquity of its articulation with the cuboid is reduced. Both the fourth and fifth metatarsal bases open up a wide articulation with the cuboid. This is clearly visualized radiographically Newman has described this altered position as hypermobility of the fifth metatarsal segment. The full implication is realized when the spot of hypermobility is related to the completely mal-aligned foot (Figs. 87, 88).

Radiographic Features of Lateral Arch Involvement

Dorso–plantar View

(1) Less than 50 per cent overlap of fourth and fifth metatarsal bases.
(2) Base of fifth metatarsal appears broadened
(3) Increased joint space between fourth and fifth metatarsals.

Clinical Considerations

The position of the cuboid that has just been described radiographically is frequently the site of manipulative effort. This is a valid movement which attempts to press the bone upwards and laterally from the plantar aspect, because this is the direction it should follow in realignment.

In examining a foot clinically to determine hypermobility, it is not enough to recognize the flexible segment The total foot problem must be investigated.

The rotation of the cuboid greatly lessens the ability of this bone, together with the fourth metatarsal to accommodate the transfer of forces from the medial arch segment This reduces foot action from a well-integrated mechanism into two separate and relatively independent structural segments.

The rotation of the fifth metatarsal places the fifth toe in a position that is liable to varus deformity and thereby foreruns a joint condition

DEMONSTRATION OF A NORMALLY ALIGNED FOOT SKELETON AND ARTIFICIALLY PRODUCED FAULTS

Use of a comparatively normal foot skeleton provided the basis for an experiment that is sufficiently demonstrative to be acceptable, although the subtle changes that take place in the insidious breakdown of foot structure in a living subject could never be produced artificially. (See illustrations in Chap. I).

The foot skeleton was given enough dippings in liquid latex to allow it to vulcanize a binding integument for the foot bones. Then the wires were cut and removed, with the exception of the one that held the metatarsals together. The foot skeleton was then pliable enough to yield to some mal-alignments when subjected to stress problems. A foot skeleton so prepared is a valuable item for any practitioner to use as a means of demonstrating foot changes visually to the patient.

First the entire foot was radiographed in its normal status in lateral and dorso-plantar positions. (Lack of normal joint constituents and intrinsic foot muscles rob the skeleton of maximum normal alignment) Next, a sufficient division of the rubberized integument was performed at vital articulations to permit an exaggerated mid-tarsal fault and a calcaneo-cuboid fault. The navicular-cuneiform articulations were left intact so the full implications of the medial arch mal-alignment were not fully realized. The relative positions of the medial and lateral arch segments were very well visualized and the relationships of the talus to the calcaneus excellently demonstrated.

Next, the lateral arch segment was separated from the medial arch segment. Each segment was then radiographed in both normal and faulty position. Again the lateral arch segment shows the most dramatic demonstration, particularly the relationship of the cuboid to the calcaneus and the fourth and fifth metatarsals. Note also the overlap of the metatarsal bases and their relative positions as visualized in the dorso-plantar view. The medial-arch segment hardly justifies the radiograph except in the visualization of the talus from a lateral view, in which we should very carefully note the completely altered shape of the talus in the new radiographic presentation. In the visualization of the calcaneus in the previous study, the dorso-plantar view provides the comparative radiographic demonstration of its shape.

The relative summations of density of the plantar tuberosities of the calcaneus together with the difference in the peroneal groove at the plantar tuberosity of the cuboid are distinctly evident in the lateral study of the normal and abnormal lateral longitudinal-arch segment.

From a radiographic standpoint, this demonstration should help the novice to master the changes of alignment that have been elaborated upon in the de-

FIG 89. NORMALLY ALIGNED FOOT SKELETON

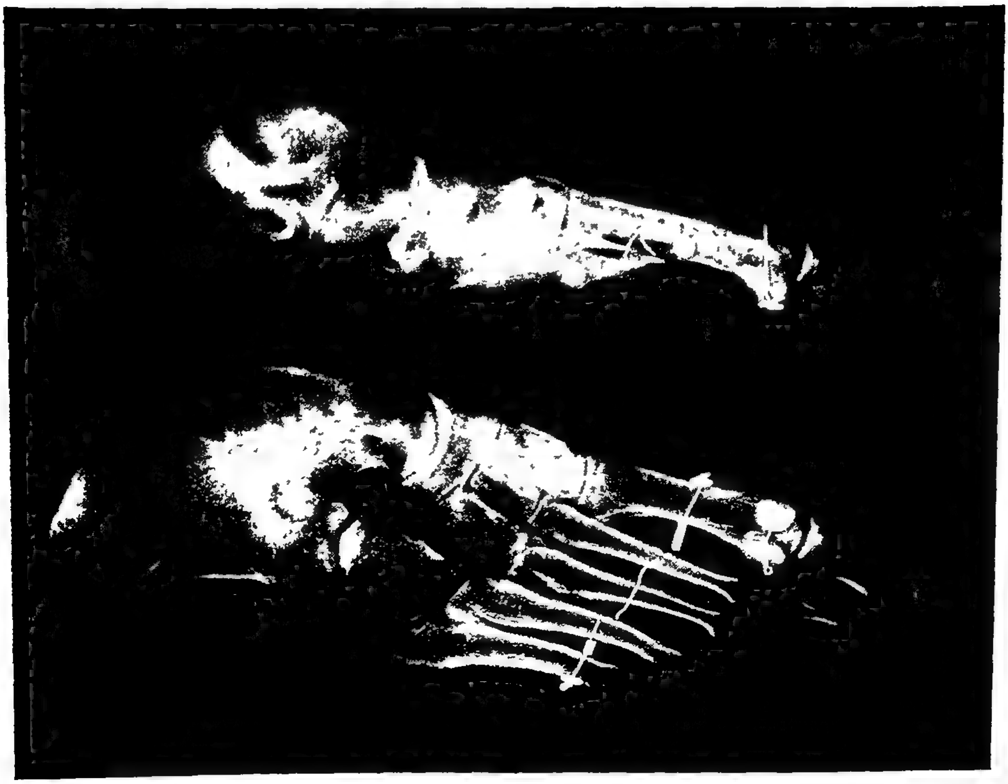


FIG 90 ARTIFICIALLY PRODUCED FAULTS

Fig 91 Normally Aligned Medial Arch Segment in Foot Skeleton

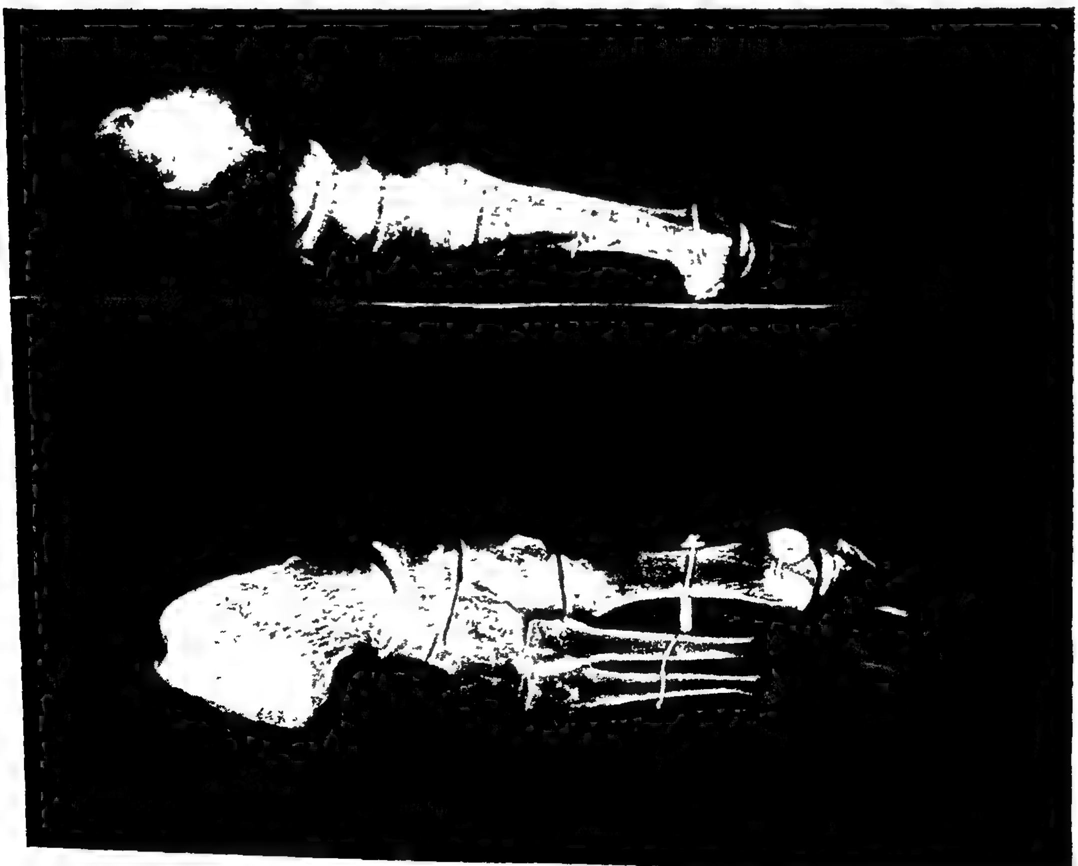


Fig. 92 Artificially Produced Involvement of Medial Arch Segment

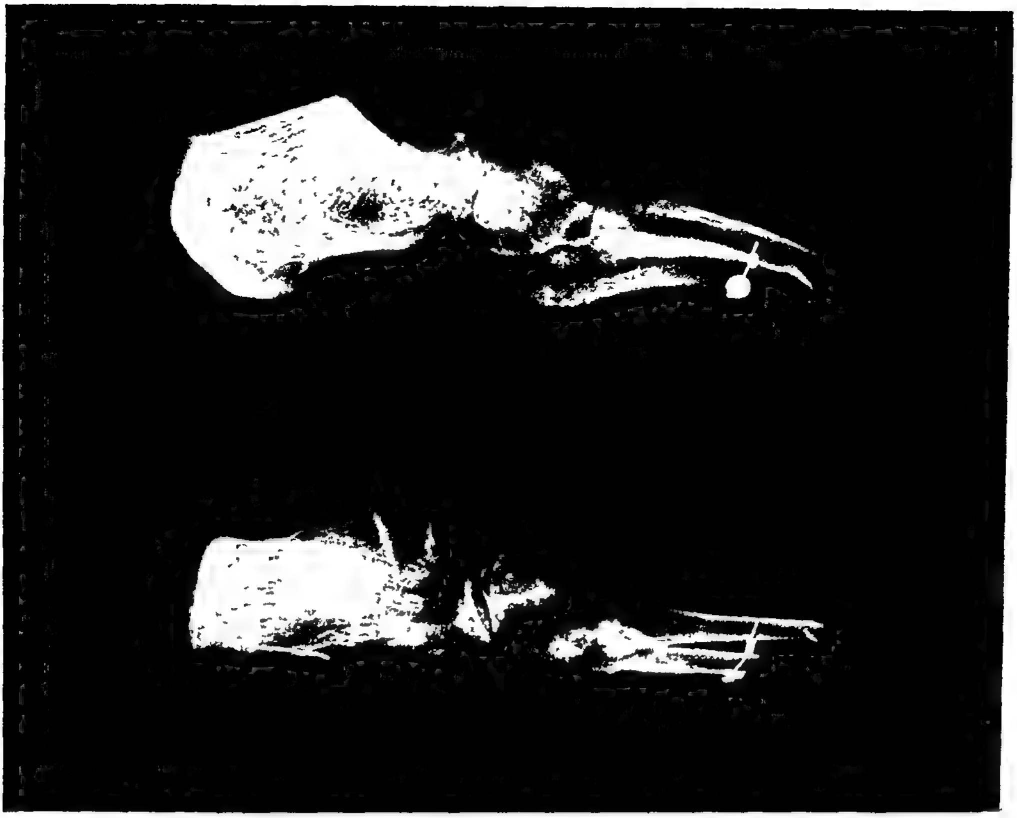


Fig. 93. Normally Aligned Lateral Arch Segment Foot Skeleton

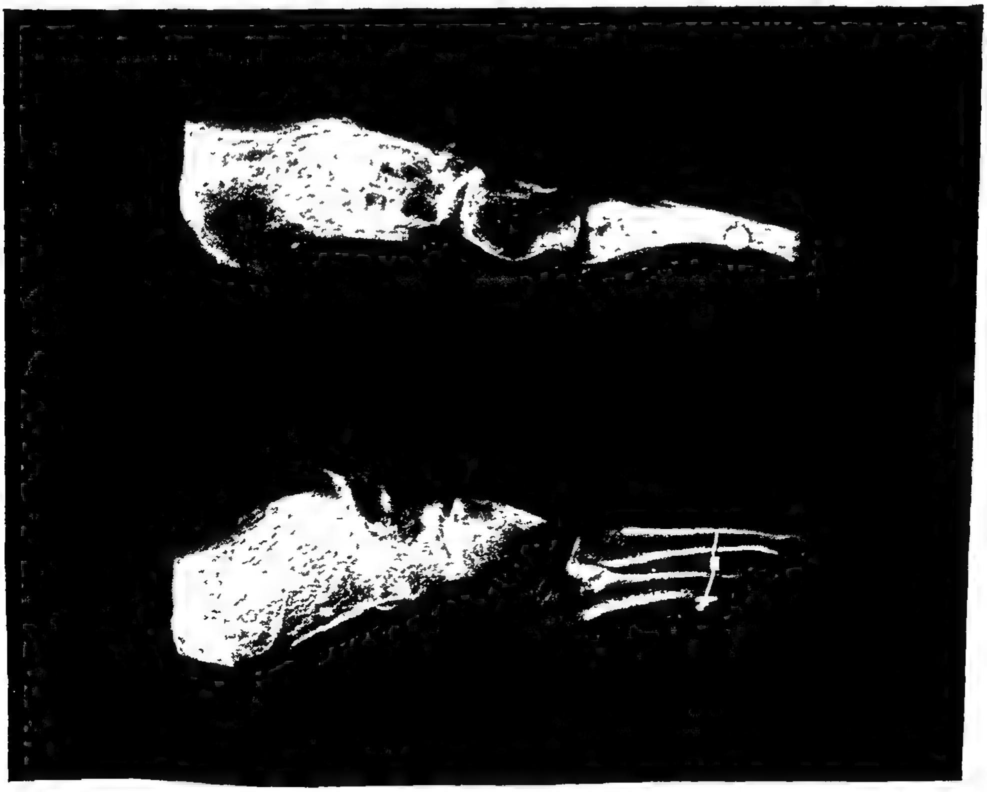


Fig 94 Artificially Produced Involvement of Lateral Arch Segment Study the following features carefully Comparison with normal, plantar tuberosities of calcaneus, sustentaculum tali, peroneal groove of cuboid, articulation of fourth and fifth metatarsals

scriptions of the fault syndromes, particularly by means of study of the individual bones as their various degrees of density appear changed in position (Figs. 89–94).

MORTON'S SYNDROME

Morton has brought to the attention of the medical world an anthropological feature of the human foot in which there is a tendency for reversion to the primate foot. The important feature is a shortness of the first metatarsal bone.

Morton feels that this discrepancy in the length of the first metatarsal is the principal cause of foot disorder. He relates this assumption first of all to the distribution of weight through the metatarsal segments, claiming that the short member shirks its normal weight burden, with a corresponding tendency of the foot to gravitate to a level whereby weight will be borne by this member. At the same time an unequal burden of work is transferred to the longer second metatarsal bone. As a result of this burden over a period of years, hypertrophy of the shaft of this bone occurs.

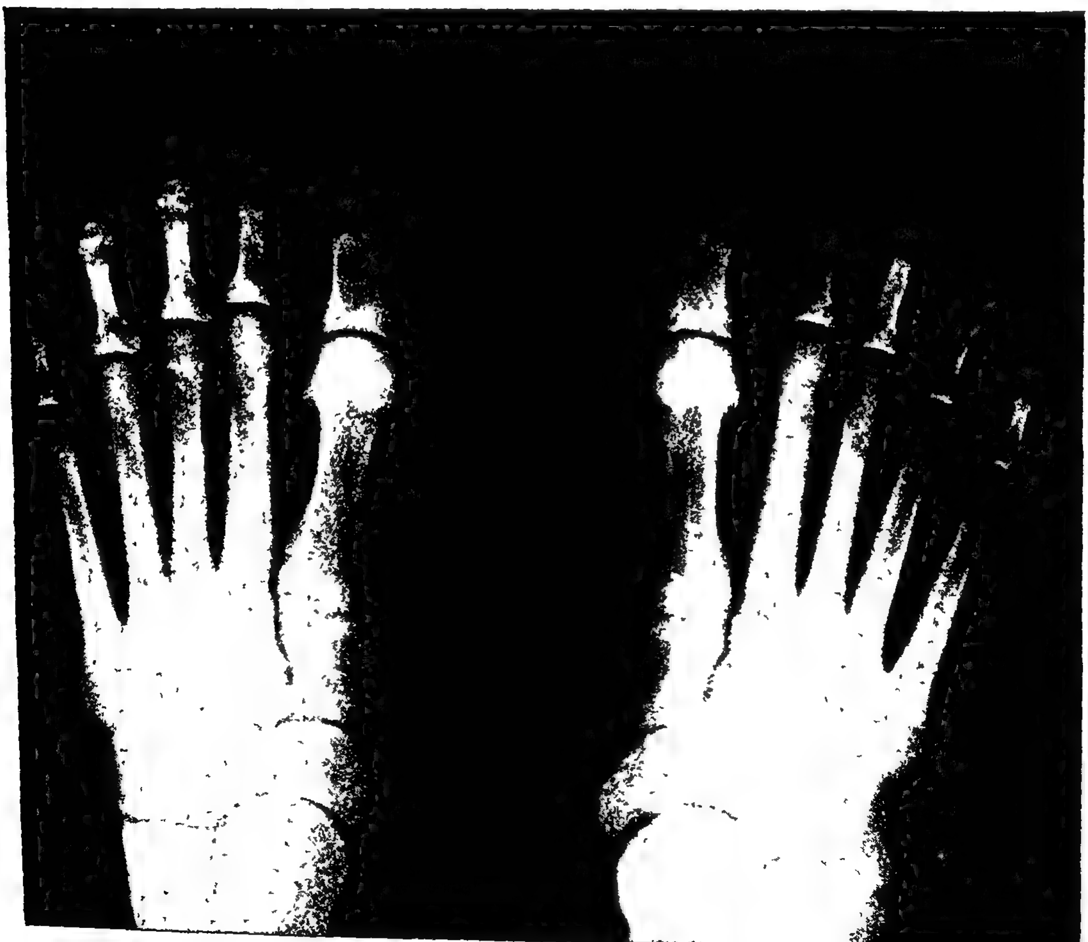


FIG. 95 MORTON'S SYNDROME. Short first metatarsal, long second metatarsal relative length; hypertrophy of second metatarsal shaft

When the foot gravitates, the first metatarsal bone and medial cuneiform separate from the articulation with the base of the second metatarsal and middle cuneiform bones, thus creating a hypermobility of this joint.

Clinically, a callus is usually found under the head of the long second metatarsal, and pain may be elicited on palpation at the hypermobile segment at its base. Morton has based his observations on the dorso-plantar radiographic view. A further feature—posterior location of the hallucial sesamoids—is considered in the same light as a relatively short first metatarsal.

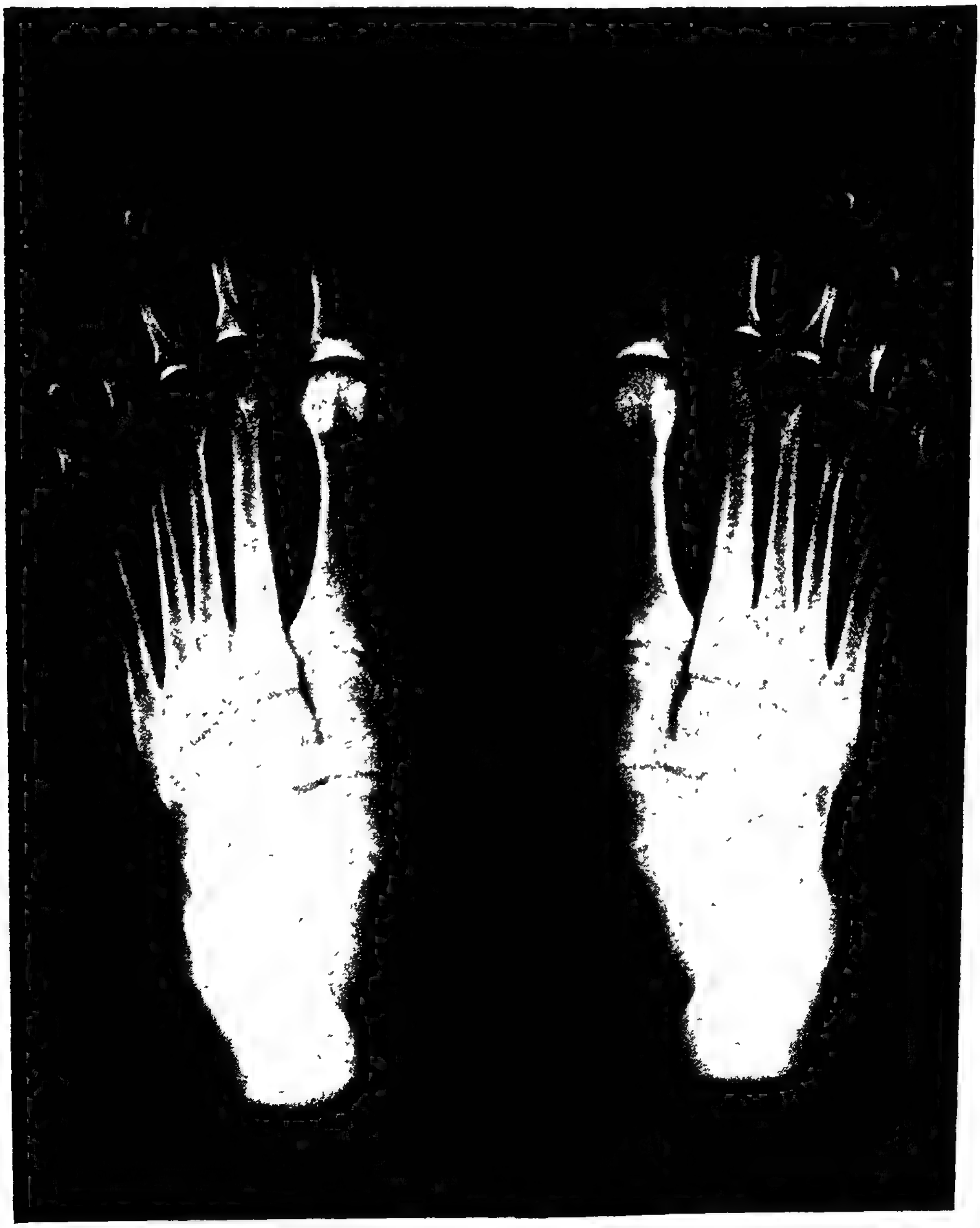


FIG 96 MORTON'S SYNDROME Short first metatarsal; long second metatarsal relative length; hypertrophy of second metatarsal shaft, hypermobility of first metatarsal segment.

Radiographic Features

(1) The first metatarsal bone is relatively short or the sesamoid bones are located posteriorly.

(2) There is hypertrophy of the shaft of the second metatarsal bone.

(3) The hypermobility of the first metatarsal segment is evidenced by the increased joint space at its articulation with the second metatarsal bone and the middle cuneiform (Figs. 95–98).

Clinical Considerations

To Dudley J. Morton goes the credit for the appraisal of the relative lengths of the metatarsal shafts and the attendant clinical problems The weight transfer over the long leverage set forth in his theory is without doubt a predominant cause of metatarsalgia symptoms.

Morton offers a solution to the structural deficiency in the form of a simple platform of leather which is placed under the short first metatarso-phalangeal

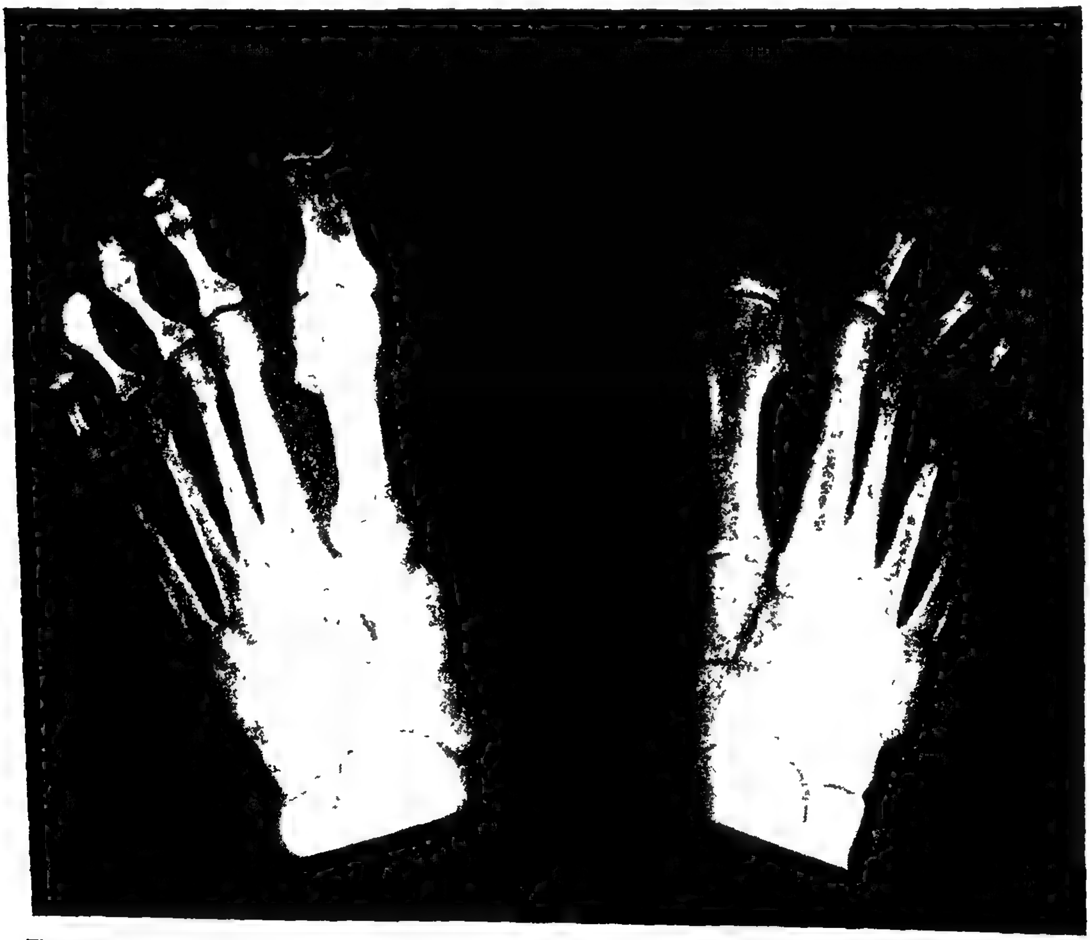


Fig. 97. Morton's Syndrome. Short first metatarsal; posteriorly located sesamoid bones; hypertrophy of second metatarsal shaft. In this case mid-tarsal fault, with forward advance of talus and inner arch segment, may tend to equalize the length ratio between first and second metatarsals Also note the deviation of the third toe

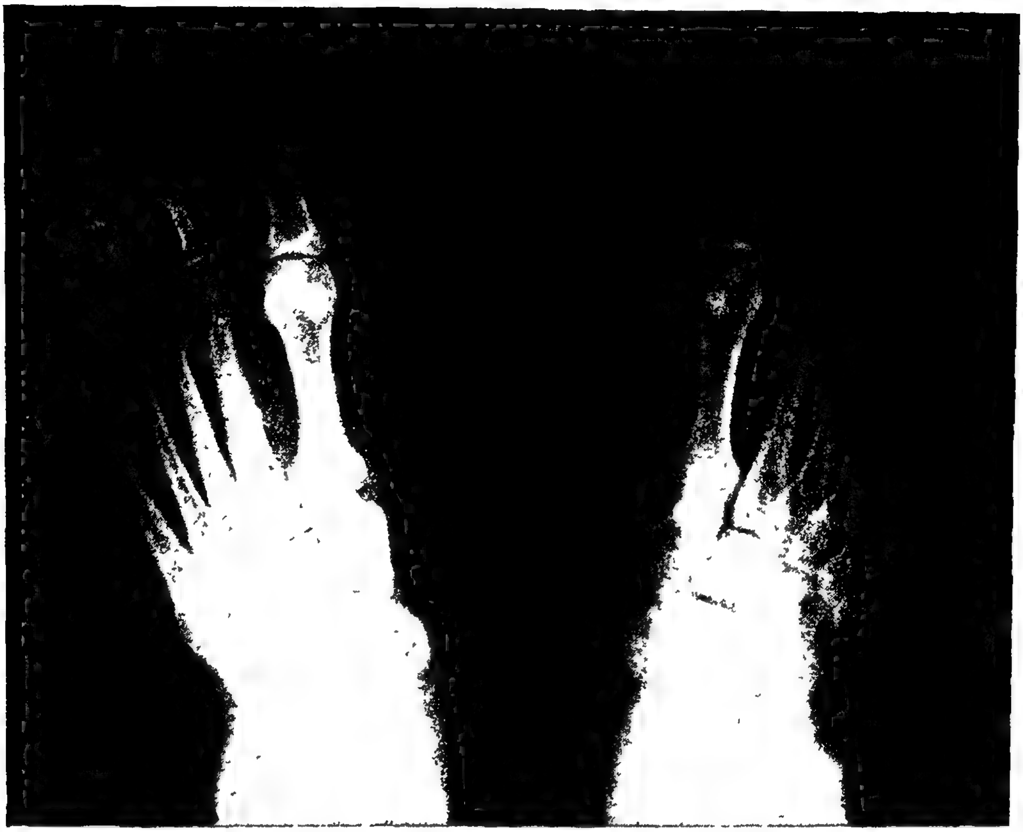


FIG 98. MORTON'S SYNDROME The lack of stress on the first metatarsal base is exemplified in this case by a diminutive girth of this bone

joint so that the leverage length might be increased to the second metatarsal. This basic principle had been adapted by many in their approach to metatarsal compensation problems.

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Chapter IV

Congenital Pes Planus

Congenital pes planus is a foot type exhibiting a characteristic osseous architecture that varies from that of the acquired form of longitudinal arch depression. The pattern of deformity is present at birth. The congenital pes planus foot may in many ways be more competent than the faulty high-arched foot.

The military might profitably use radiographs to differentiate the acquired, faulty type of pes planus from the congenital type of pes planus that should in no wise hamper a man in military service. The foot imprint and visual inspection of arch height that have long been used as criteria should be abandoned.

Congenital pes planus occurs with high frequency among the South African Bushmen, and the American Negroes. However, the circumstance of an isolated case of congenital pes planus in a Caucasian family with otherwise normal foot types suggests a different problem, commonly designated medically as "idiopathic."

The idiopathic problems suggest consideration of the following possible etiological factors:

(1) A defect in the basic genes responsible for normal foot morphology.
(2) A defect in the embryonic process of development.
(3) An intrinsic arrest in the normal changes in the relationships of the foot bones during the process of fetal development.
(4) The position of the fetus during intra-uterine development.
(5) The inability of the infant to resolve minor deformities due to restrictions of soft tissues, both ligamentous and muscular, following birth.
(6) Specific muscular abnormalities of the fetus which influence the position of the foot bones

The quest for more knowledge of embryonic problems is emphasized by Patten in his discussion of the complexity of the causative factors in abnormal development in general. He suggests that much more data in several avenues of research are needed to draw even a tentative conclusion as to their existence.

Of the present theories advanced, Bechtol and Mossman have conclusively demonstrated a muscle abnormality in a fetus in which fibers disintegrated prior to birth, leaving a residual deficiency that established a muscle imbalance responsible for club foot.

This writer would like to explore the factor of intrinsic arrest in the normal changes in relationship of foot bones during embryonic and fetal development

as another substantiated factor in congenital pes planus. As the foot develops in shape, it undergoes some profound changes in alignment. According to Keibel, in its earliest form the embryonic foot lies on a straight line with the leg and thigh (Fig. 99). As the heel takes shape the foot remains in an equinus position. Later, the soles of the feet turn medially, which fixes them in an equinovarus position. In the final months of fetal life, the foot becomes flexed and slowly everts so that at birth it assumes a relatively normal alignment.

The internal arrangement of the bones during embryonic development places the talus alongside the calcaneus in the early stages and the metatarsals on a parallel plane. In the final stages of fetal development, the talus assumes its normal position atop the calcaneus and the transverse tarsal arch is accentuated with the metatarsals on their normal levels.

If the foot should fail to complete every phase of embryonic and fetal development, at birth the foot would exhibit a deformity depicting the arrested stage of morphological development Since the relationship of the talus and calcaneus in congenital pes planus reverts to an early stage of fetal development, it seems logical to include this minor deformity in this category

The roentgen impression of pes planus establishes a typical arrangement of the bones that provides a description of this foot type.

Radiographic Impressions

Plantigrade Calcaneus· Lateral View. The calcaneus assumes a plantigrade position in which its inferior aspect lies almost parallel with the weight-bearing plane (Fig 100). In extreme cases the anterior portion may even lie on a plane lower than that of the plantar tuberosities This lowers the entire alignment of the foot to a plantigrade position. The calcaneus is everted

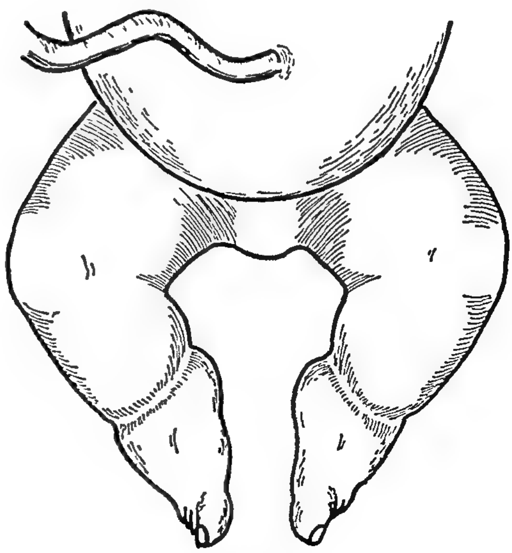

Fig. 99. Position of Fetal Foot at 2–3 mo is Straight with Leg. (after Keibel)

Fig. 100. Plantigrade Pitch of Calcaneus in Congenital Pes Planus

Shape of the Calcaneus: Lateral View. The shape of the calcaneus, in which there is a marked cortical condensation of the plantar aspect of the anterior portion of the bone, is characteristic. This condensation of the bone may change its configuration to resemble a tuberosity. In effect, this portion of the bone bears weight in the same manner in which the normal tuberosities of the calcaneus bear weight (Fig. 101).

The lessened function of the posterior portion of the bone often results in a noticeable diminutive size.

Index of Calcaneal Shape: Lateral View. The total posterior subtalor joint margin that is visualized in the lateral view subtends an angle with the supero-posterior aspect of the calcaneus, and in the pes planus foot type the angle is far more broad than in the higher arch forms (Fig. 102). *This is an indication of the variance in calcaneal shape that determines to a great degree the foot type.*

Talo-calcaneal Relationship. Severe medial rotation of the talus is visualized in the dorso-plantar view in which the head of the talus practically escapes support of the anterior portion of the calcaneus, and the sustentaculum tali is ineffective in support. An opening which frequently appears at the mid-junction of the talus and calcaneus indicates the loosely bound situation (Fig. 103).

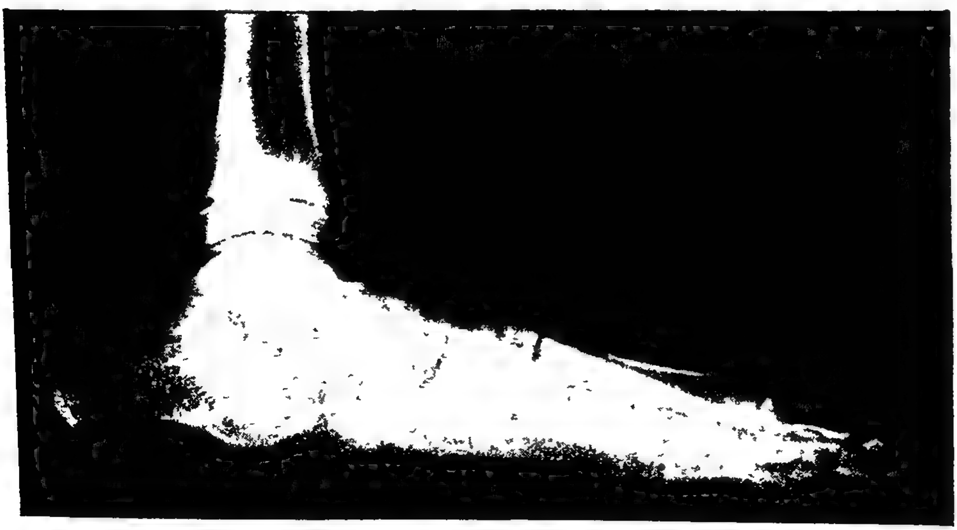

Fig 101 Congenital Pes Planus Plantigrade calcaneus; condensed and convex anterior portion of calcaneus—a weight transmittal area; diminutive posterior portion of calcaneus; mid-tarsal fault.

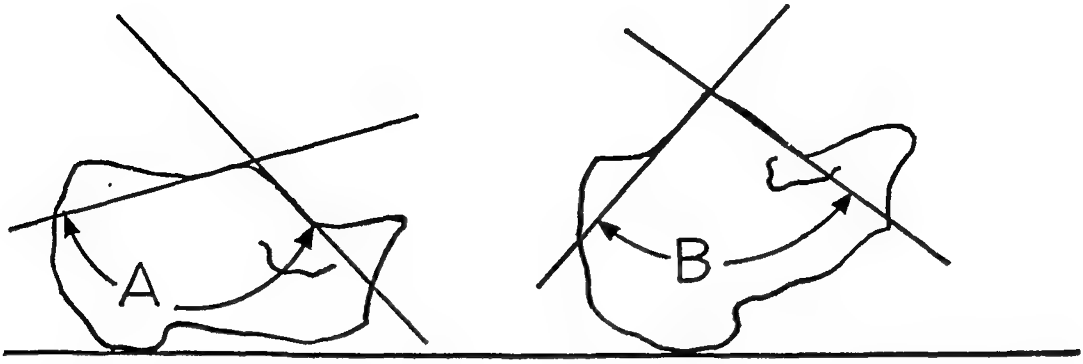

FIG 102 CALCANEAL SHAPE—AN INDEX OF ARCH HEIGHT. (a) Low arch calcaneal shape (b) High arch calcaneal shape.

The severe medial rotation of the talus is more difficult to appraise from the lateral view There is a geometric shortening of the neck of the talus because the central ray passes at a right angle to the obliquely placed bone.

Pseudo-normal Mid-tarsal Joint Line. The mid-tarsal joint line remains on planes that simulate a normal relationship between the talus and calcaneus in both the lateral and dorso-plantar views This is true because there is much medial rotation of the talus and little forward displacement. Consequently, the joint line remains continuous although the bony elements are badly spread in the width of the foot In this foot type there is minimum elongation

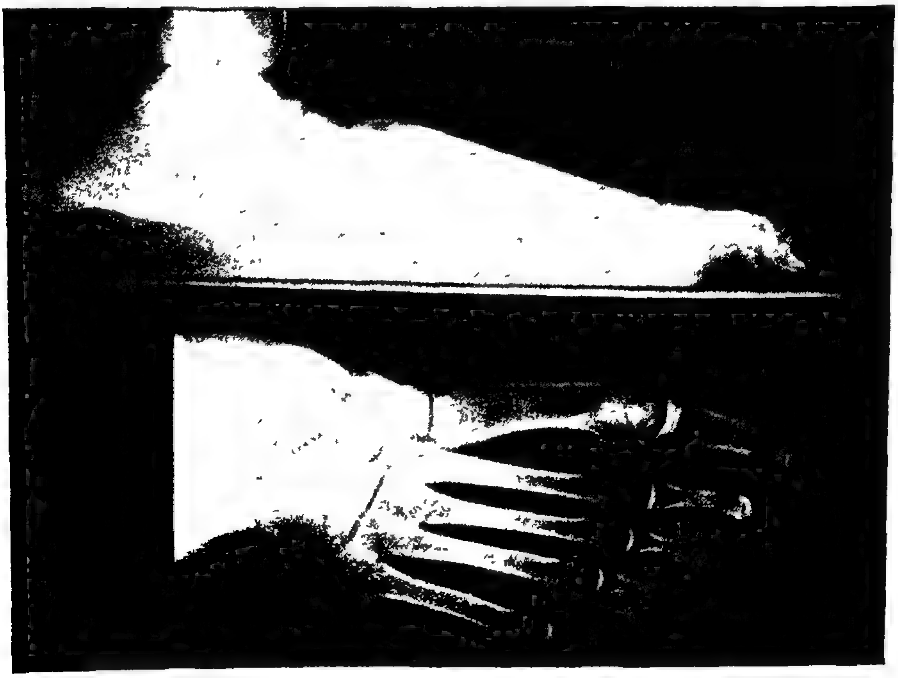

FIG 103 CONGENITAL PES PLANUS Severe medial rotation of talus, pseudo-normal mid-tarsal joint line, head of talus flattened, tarsal arch spread, fifth metatarsal loosely articulated, straight compensated forefoot

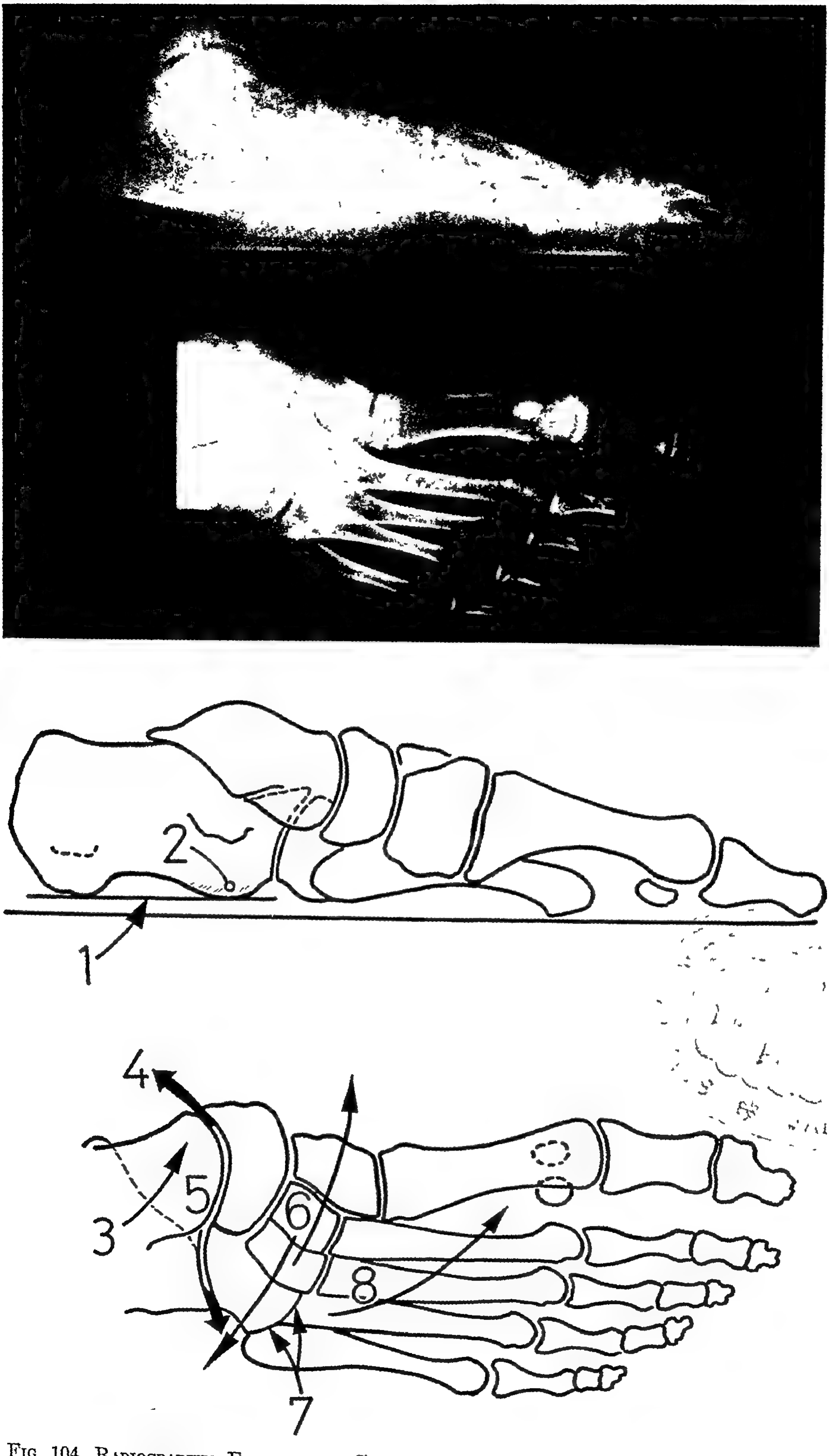

FIG. 104 RADIOGRAPHIC FEATURES OF CONGENITAL PES PLANUS. (1) Plantigrade calcaneus (2) Anterior portion of calcaneus condensed and convex (3) Medial rotation of talus (4) Pseudo-normal mid-tarsal joint line. (5) Head of talus flattened (6) Tarsal arch spread. (7) Fifth metatarsal loosely articulated (8) Forefoot compensated into adduction

Shape of Talus. Alterations in the shape of the talus consist mainly in a flattening of the head of the bone in response to the unusual position of the bone. This creates functional disturbance.

Transverse Tarsal Arch. The severe rotation of the talus carries the navicular to a medial position also, and the cuboid is rotated and spread apart from its usual position. The fifth metatarsal is loosely articulated. These changes predispose the transverse tarsal arch to a flattening and spreading that places the cuneiforms on a nearly parallel plane instead of in a tightly knit arch.

Status of the Forefoot. The alignment of the metatarsals and toes is in abduction if the basic alignment is followed in accordance with the line of least resistance. Over-development and frequent spasm of the peroneal muscles contribute to this abduction. This alignment may be appraised by relating the axis of balance to the relative positions of the metatarsal shafts. The valgus position of the second metatarsal may divert the axis of balance somewhat.

There is a tendency for the individual to compensate for the poorly poised pes valgo planus type of foot by adducting the forefoot. This is achieved by rotating the leg. In these cases, the metatarso-phalangeal segments assume a varus position in spite of the eversion of the hindfoot. This compensated foot develops early in childhood, and bone shapes are well fixed by adulthood. Actually, the adduction of the forefoot bones appears in the internal arrangement of the bones as seen on the radiograph—from an outward appearance the foot lies straight.

Radiographic Features of Congenital Pes Planus (Fig. 104)

(1) Plantigrade calcaneus.
(2) Anterior portion of calcaneus condensed and convex.
(3) Medial rotation of talus.
(4) Pseudo–normal mid–tarsal joint line.
(5) Head of talus flattened.
(6) Tarsal arch spread

CONGENITAL PES PLANUS WITH ACQUIRED DEFECTS

Through the course of a lifetime, the congenital pes planus receives more or less constant abuse. However, in spite of the mechanical disadvantage under which this foot functions, it maintains its typical pattern surprisingly well. Nevertheless, defects occasionally develop in this type of foot.

Adduction of the forefoot has been described as a compensatory change. Although it might be considered an added defect, in reality this altered alignment is distinctly a better functioning one.

The characteristic features of mid-tarsal fault may be added to the congenital pes planus The chief features of forward displacement of the talus and alteration of the normal mid-tarsal joint line are exemplified to a mild degree since there is little chance for these faults to develop in a foot lying on so low a plane. These features do occur occasionally and indicate a further weakening of the ligamentous integument (Figs. 105, 106).

TABLE 1

	Acquired Arch Depression	Congenital Pes Planus
Calcaneal position	Assumes a pitch of 10° or better with the weight-bearing plane	Lies at a pitch of less than 10° with the weight-bearing plane and usually parallel to it
Shape of calcaneus	Concave from plantar tuberosities to anterior process	Markedly convex and condensed from the plantar tuberosities to the anterior process
Mid-tarsal joint	Altered joint line. Talus juts forward	Pseudo-normal joint line. Medial displacement of the talus

Clinical Considerations

The crux of a differential diagnosis between an extreme acquired depression of the longitudinal arch and a congenital pes planus is gained through a careful study of the position and shape of the calcaneus, plus a careful evaluation of the mid-tarsal joint.

The serviceability of the congenital pes planus depends upon an early forefoot adduction-compensation that will permit parallel gait and freely functioning knees. In gait the foot is carried straight forward in a shuffling manner in-

FIG 105 EXTREME CONGENITAL PES PLANUS Posterior portion of calcaneus at higher pitch than anterior part

FIG 106 EXTREME CONGENITAL PES PLANUS Medial arch segment plantigrade, abduction, no compensation, all fault syndromes added.

stead of with a graceful movement The rotation of the calcaneus tends to push the heel counter over the lateral side of the shoe, and the weight forces, carried medially on the foot, break down the medial border and shank of the shoe. This non-elastic gait provokes direct jarring, which eventually leads to minimal traumatic arthritic changes that are profound and may be painful in late adult life.

Since acquired faults may develop within this plantigrade foot type, it is logical and practical to provide as much support for the congenital pes planus as the flexibility of the foot will permit. In many cases, a reinforced shoe is all that can be tolerated—in other cases a Whitman plate is acceptable. In any case, a very strongly constructed shoe will be needed to undergird any supporting device The untreated case is likely to develop peroneal spasm and kindred soft-tissue problems. The calf group of muscles is invariably shortened in this foot type by means of the span to its attachment in the posterior aspect of the calcaneus, and this prevents ease of flexion in the foot at the ankle A straight forward shuffling gait is the outcome when the foot is in compensated adduction, whereas a flailing gait with out-turned feet and excessive motion at the mid-tarsal joint occurs in the basic pes planus deformity

Several surgical reconstructive procedures have been used to improve this foot type. Leavitt has developed a subtalor arthrodesis that has yielded good results in selected cases His radiographic demonstrations show a restored mid-tarsal joint and talo-calcaneal relationships.

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Chapter V

Pes Cavus

Much attention has been given to the foot types that gravitate when ligament weakness and muscular instability predominate. Our attention will now be shifted to those distortions of the foot in which the arch height is increased.

Simple pes cavus is more the result of faulty bone shapes, short fascial structures, and muscle imbalance than of ligament weakness. Joint excursions are carried to their extremes and the foot held in exaggerated arch formations (Fig. 107). Secondary extension deformities of the toes exceed their normal range of motion, which results in damage to joint capsules and ligaments (Fig. 108). Intrinsic foot muscles, especially the lumbricales, interossei, and short toe flexors become ineffective. Frequently basic bone shapes establish the simple cavus form of the foot.

Complicated pes cavus encompasses a wide range of deformity and disability. The various congenital talipes deformities are included in this group. The bizarre foot distortions created by myleodysplasias, spina bifida, and other central nervous system pathology are seen occasionally (Fig. 109). Very frequently, the post-poliomyelitis cavus deformity is encountered in routine office practice (Fig. 110). Bone shapes are distorted into unbelievable creations. The impost of weight and altered function following surgical intervention sometimes causes bone changes. The continued faulty attitude following trauma of the foot may lead to cavus shapes. According to Jones, even the continued weight of bedclothes for 6 months or longer may create pes cavus as a result of adaptive shortening of the plantar fascia. Cole claims that, as growth takes place, the individual bones of the foot become intrinsically deformed through contractures of plantar structure and muscle imbalance

From a more specific etiological standpoint, pes cavus may be either congenital or acquired. The congenital problems fall into two categories: those that represent imperfect development of the foot with the structure fixed in the equinus position and those that have been influenced by neuro-muscular deviations that have restricted the shape into the aborted position of extreme cavus with contracted toes. Instances of imperfect development may be related to the same factors controlling morphological progression of the embryo and fetus that were described in the previous chapter, except that a different stage of development and a different effect are involved. The isolated idiopathic pes cavus falls into this category. The familiar hollow foot that exceeds the normal range of arch height is an inherited type of highly differentiated foot. Also included in con-

FIG 107 PES CAVUS—SIMPLE CONGENITAL TYPE

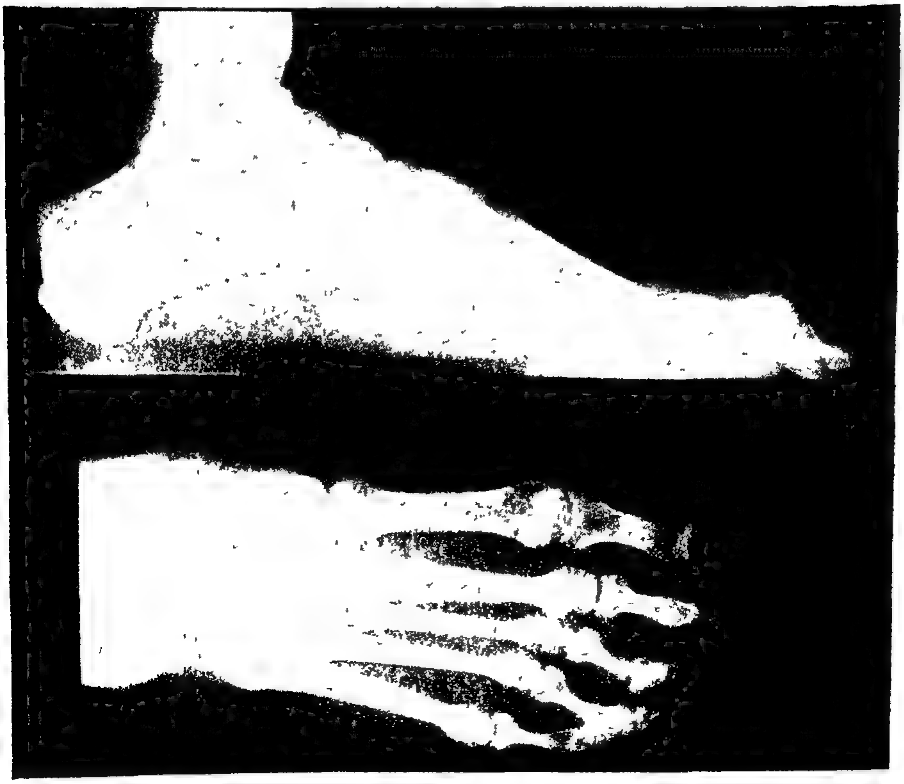

FIG 108. PES CAVUS—CONGENITAL TYPE. Toe contractions
(Courtesy of Dr Wm F. Eads)

FIG 109. PES CAVUS—BIZARRE CONGENITAL MONSTROSITY
(Courtesy of Dr T L Lauer)

genital problems are deformities induced by Friedriech's disease, congenital syphilis of profound neuro-muscular complication, and all of the spastic paralyses and other cerebral problems that may induce muscular imbalance to such an extent as to create pes cavus deformity.

Acquired pes cavus is usually the result of some neurological disturbance of a paralytic type such as poliomyelitis which is the chief offender. Very often the patient who exhibits a pes cavus that he says has been his lot as long as can be remembered may not have a congenital condition at all; rather, it may be the end result of an abortive type of poliomyelitis. Shaeffer believes that cavus deformity follows poliomyelitis where paralysis has been completely cured. Cavus feet are frequently associated with Dupuytren's contracture and acquire greater deformity with passing years. Other instances of acquired forms are discussed as complicated pes cavus.

PATHO-ANATOMY

Anatomically, Duchenne segregates cavus foot problems according to the muscle conditions involved: (1) cavovalgus foot; an isolated contracture of the

Fig 110 Pes Cavus—Acquired Type. Poliomyelitis deformity

peroneus longus, (2) calcaneocavus with lateral torsion; a weakness of the triceps surae with normal strength of the peroneus longus, (3) calcaneocavus with medial torsion; an isolated contraction of the long flexors of the toes, and (4) direct calcaneocavus; a simultaneous contraction of the peroneus longus and the long flexors of the toes Steindler emphasizes Duchenne's analysis by this succinct statement, "Cavus deformity is the expression of disturbed muscle balance, with a surplus of power in favor of the muscles which shorten and heighten the long arch, that is, the toe flexors and the peroneus longus when unopposed by the gastrocnemius and the tibialis anterior"

The calcaneus, in which there is an extremely broad angle between the subtalor articulation margin and the supero-posterior surface of the calcaneus, is pathognomic in cavus feet This bone shape tends to deprive the tendo achilles of its effective leverage so that the apex of the cavus will be found at the talonavicular joint. Gilroy claims that at two years of age the destiny of any foot can be determined by the position of the calcaneus; that is, one with long leverage for the tendo achilles will eventually have a low arch and one with short leverage will have a high arch. Continuation of a faulty attitude produces bone deformity. This theory is substantially sound, although there are many extrin-

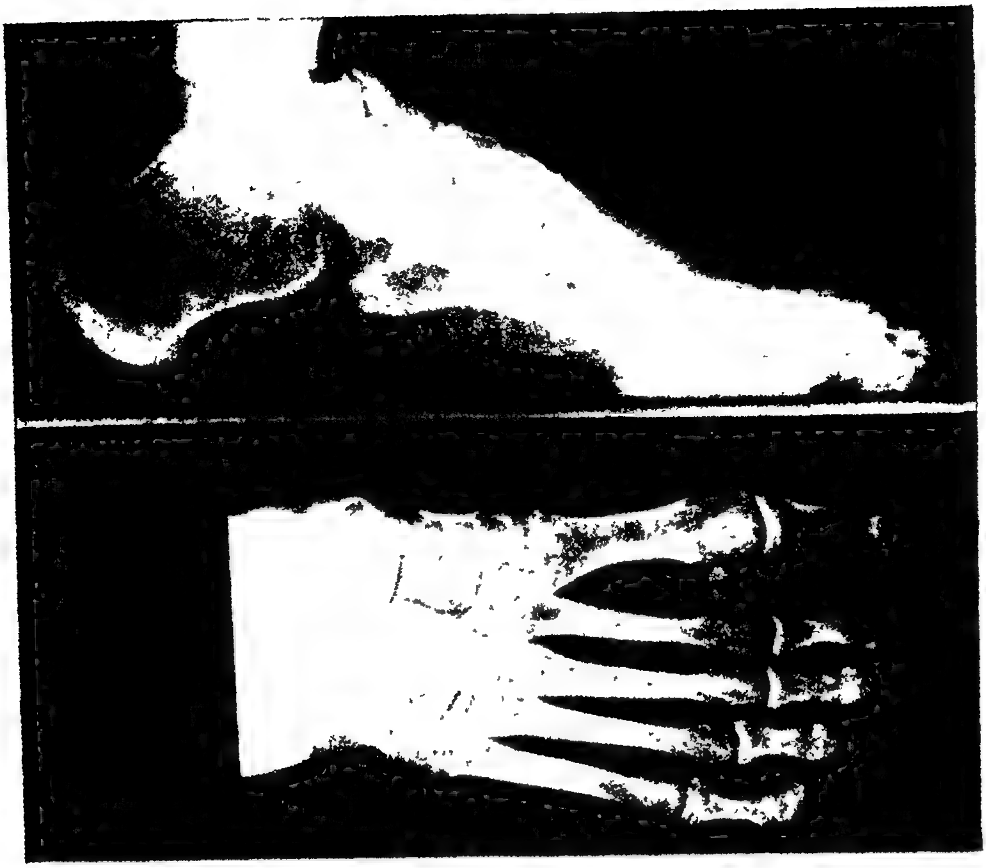

FIG. 111. PES CAVUS—FIXATION BY SURGICAL INTERVENTION

sic factors that must be considered, and more than one short calcaneus has been observed in cavus feet.

Brewster and Larson feel that loss of ankle motion contributes to a stiff foot-and-heel walking gait and that, concomitantly, the long toe extensors become overactive in an attempt to elevate the dropped forefoot and to keep the toes from touching the floor in walking. When the extensors are overactive, the intrinsic muscles and short flexors are used less and become atrophied. With this loss, there is nothing to prevent the toes from being cocked-up This is borne out clinically. Cocked-up toes go hand in hand with depressed metatarsal heads with resulting quick development of painful bursae.

In the pes cavus foot type, varying degrees of forefoot drop may be developed, irrespective of the hindfoot status. Cole considers this the basic anatomical problem. Brockway indicates that the apex of the cavus will be situated at the navicular-cuneiform joint when forefoot drop is predominant.

Radiographic Impressions

Radiographs of the cavus foot are imperative for a thorough understanding of the problem, especially since the external conformation of the foot can be very misleading. A cavus foot condition may be created by surgical intervention such as tarsal resection, with resultant fusion and reconstruction of the bones and joints (Fig 111). When the details of alterations are visualized radiographically, the limitations of this foot may be fully understood, whereas clinical examination would surely fail to show the reason for foot insufficiency.

Brockway insists that weight-bearing foot roentgenograms are necessary to determine the apex of the deformity, whether it be navicular-cuneiform with forefoot drop or talo-navicular apex in cases of long heels. Cole asks for x-ray studies of the range of flexion and extension to prove forefoot drop in claw-foot types of pes cavus.

Radiographically, the congenital and acquired types of cavus may be practically indistinguishable. The deformities may be just as bizarre in a long-standing polio deformity as in a problem due to spastic paralysis. Disuse atrophy of bone is often visualized in those cases in which proper foot function is chronically suspended.

Irrespective of its etiology, the simple pes cavus presents a classical osseous architecture that may be evaluated radiographically. The complicated forms are merely exaggerations of the basic form with severe distortions.

Radiographic Features of Simple Pes Cavus (Fig. 112)

Lateral View

(1) The interpretation depends upon the lateral view.
(2) The calcaneus lies on a plane that is acutely angulated with the weight-bearing plane above 30°.
(3) The fifth metatarsal also assumes a high plane above the weight-bearing plane
(4) The mid-tarsal joint is normal.
(5) The subtalor joint spaces are accentuated in detail.
(6) The apex of the dorsal aspect of the longitudinal arch may be at either the talo-navicular joint or the navicular-cuneiform one.
(7) The shape of the sinus tarsi is exaggerated.
(8) The shape of the calcaneus presents an acute angle as the line of the posterior subtalor joint subtends with the supero-posterior aspect of the calcaneus.

Dorso-plantar View

(1) The tarsal components are usually in normal alignment.
(2) There is radiographic shortening of the metatarsal shafts due to the high pitch of the shafts.
(3) In cases of contracted toes there is closure of the inter-phalangeal joints.

Radiographic Features of Complicated Pes Cavus

(1) The apex of the arch is at the talo-navicular joint in the long or relaxed calf muscle group.
(2) The apex of the arch is at the navicular-cuneiform joint in cases of severe dropfoot.
(3) Distorted bone shapes, usually compressed and angular, are found.
(4) Calcaneo-cuboid fault with exceptional bone shapes is usually present.
(5) There is disuse demineralization of a generalized character.

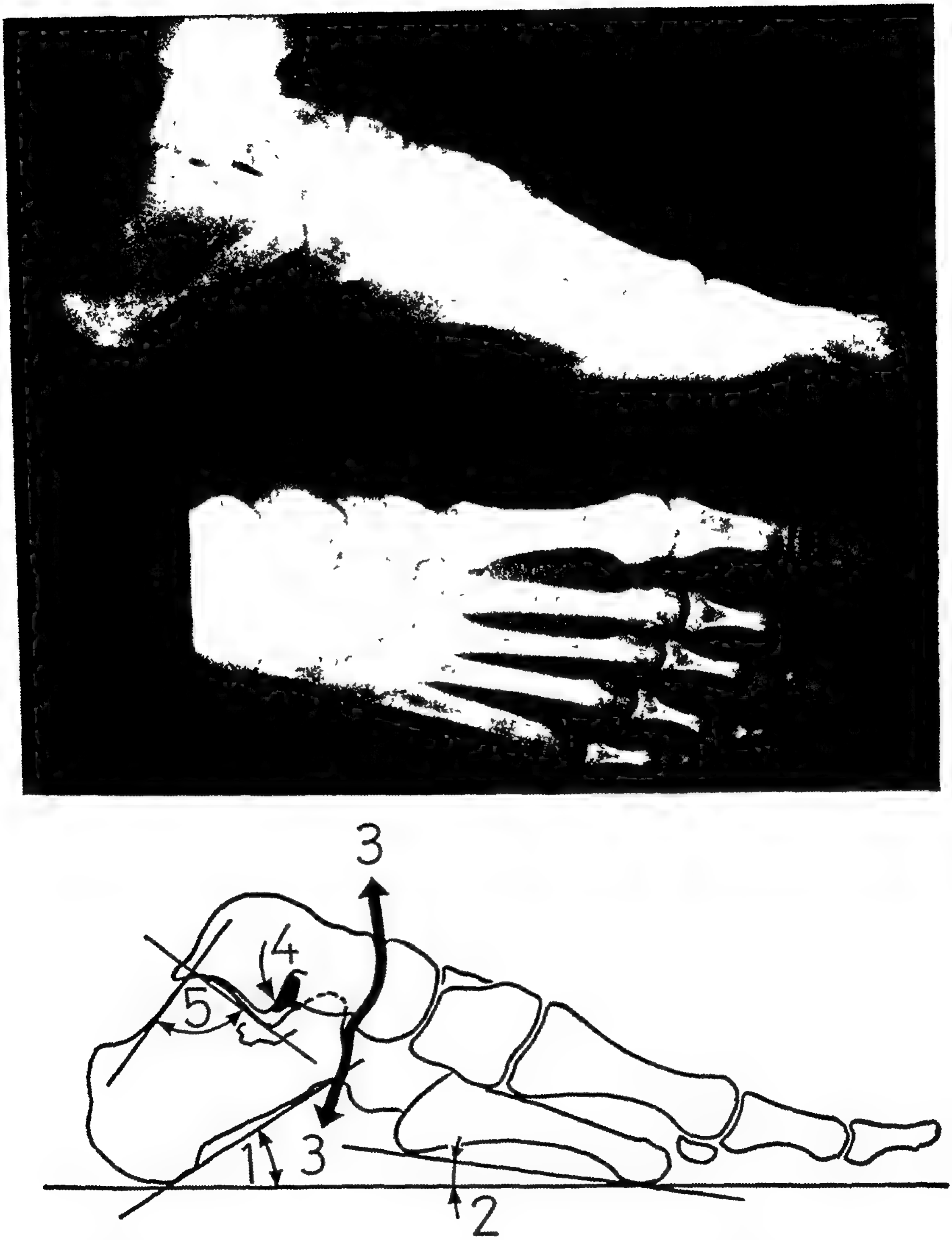

FIG 112 RADIOGRAPHIC FEATURES OF PES CAVUS. *Lateral view* (1) Pitch of calcaneus above 30 degrees (2) Fifth metatarsal at high pitch (3) Mid-tarsal joint line normal (4) Subtalor joint and sinus tarsi accentuated (5) Acute angle between subtalor joint and long axis of calcaneus.

(6) In cases of inversion and medial torsion there is hindfoot inversion with the head of the talus overlapping the anterior portion of the calcaneus laterally.
(7) In cases of medial torsion, forefoot adduction is present (Fig. 113).
(8) Contracted toes.

Clinical Considerations

The highly arched foot frequently presents orthopedic problems that are as difficult to manage as depressions of the longitudinal arch. Fascitis of the short plantar soft-tissue structures is common, as are excessive weight-distribution lesions to either or both heels and the metatarsal area. There are also contractural deformities of the toes because of the direct-line pull of the extensor tendons in this type of foot architecture, plus bursitis and irritations on the dorsum of the foot from shoe pressure, and retro-calcaneal bursitis in connection with the unusual calcaneal shape and shoe pressure. Instability of the foot because of a lack of weight distribution along the lateral border of the foot may be present, as well as non-elastic gait resulting from limited ankle motion.

All of these problems point up the importance of something more than a casual consideration of simple pes cavus as a mere morphological foot type.

Brockway claims that in cases of pes cavus adaptive ligamentous contractures occur as early as 8 to 9 years of age. Although systematic stretching and stimulation of weak muscle groups is advocated for early cases, results are slow in forthcoming. At the Cleveland Foot Clinic, the author followed the routine of

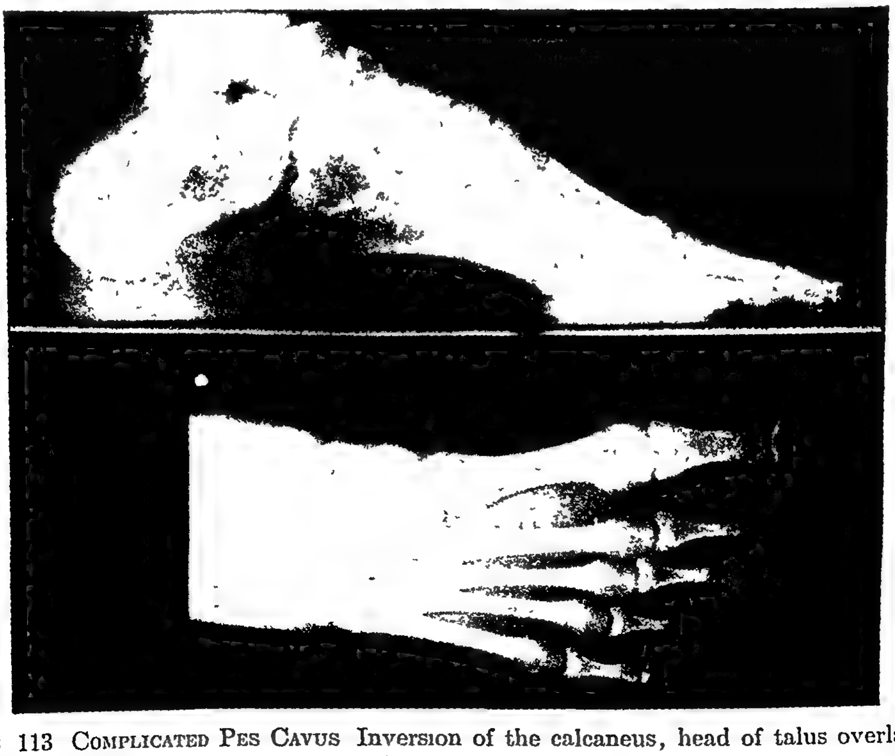

FIG 113 COMPLICATED PES CAVUS Inversion of the calcaneus, head of talus overlaps anterior portion of calcaneus excessively, forefoot adduction

using a Schuster stretching device under rigid control, for 18 months, on a typical Shaeffer claw-foot type of pes cavus in an 18-year-old girl, with poor results. This isolated case indicates the strength of adaptive contractures. Many surgeons feel that division and stripping of soft tissues is of little avail in the correction of this condition.

Many surgical procedures for the control of this problem have been devised. Cole advocates transplanting the toe extensors to the cuneiforms to aid in keeping the sole flat and in preventing progressive cavus. In addition, he uses an anterior wedge osteotomy to improve function. Brockway follows two premises in his surgical correction of talipes cavus deformities: (1) Since preservation of lateral motion is of fundamental importance in the true cavus foot, wedge osteotomies are useful as long as the mid-tarsal joint is preserved, (2) stability is more important than motion in postpolio cases and is achieved by triple arthrodesis. Brewster and Larson also believe that triple arthrodesis plus transplantation of the long extensor tendons of the toes to the metatarsal necks obtains the best results. They aim to accomplish three things with their surgical reconstruction: (1) The talus is reshaped to elevate the forefoot so as to flatten the arch, (2) the pitch of the calcaneus is changed to reduce contracture and to increase the leverage of the tendo achilles, (3) the foot is shortened to relax tightness of the plantar fascia and to lessen the cocked-up position of the toes by relaxation of the contracted tendons.

In general foot practice the simple non-deforming type of pes cavus is most frequently seen. When the cavus foot is not complicated by toe contractions, accommodation of the high arch contour with a saddlelike appliance to increase weight distribution over a greater area of the foot tends to relax the contracted plantar fascia and to lessen the abuse of the metatarso-phalangeal area. If the case tends to invert, foot balance should be achieved by the incorporation of adequate raise on the lateral border of the appliance. When the sub-metatarsal prominence of the first segment is manifested plantarly, because of contraction of the peroneus brevis, the foot appliance should be extended under the lesser metatarsals and should be of a thickness sufficient to take weight-bearing and to relieve the first metatarsal area from excessive impost. Rehabilitation of calf muscle should be instituted according to the individual needs of the case, as should also complete muscle re-education through electrotherapy, resistive exercise, and gait training. When the case is complicated by toe contractures, some small measure of help may be afforded by utilizing felt purchase wedging under the toes so that the interossei, lumbricales, and short toe flexors may be encouraged to become active. These devices may be utilized up to their maximum effectiveness and then duplicated in flexible plastic as a permanent type of toe retainer. This work will be given more emphasis, under orthodigital problems, in a later chapter (Chap. VIII) The much abused "metatarsal pad" is not advocated to reduce toe contractions since it rarely achieves the results expected. It tends to push up into the soft tissues posterior to the metatarsal heads and to cause atrophy in direct proportion to the thickness of the pad In order for a pad of this type to be effective, it must actually raise the metatarsal shafts. This requires a massive pad to achieve the desired result. Due to its rocker action,

the metatarsal bar affixed to the sole of the shoe is more effective in causing the toes to stretch out in flexion.

The complicated pes cavus of considerable deformity always requires careful management when conservative measures are employed. Plaster foot models should be made and the appliance should be carefully designed to accommodate the foot in balance and to provide relief of specific areas of excessive weight distribution. Special shoes are sometimes the simplest solution when there is considerable discrepancy in the size, shape, and form of the feet.

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Chapter VI

Pes Adductus

Deviations of the forefoot from the longitudinal axis of the foot have been identified in connection with a variety of foot problems. Adduction is present in the compensated mid-tarsal fault and the pes valgo planus foot At the other extreme, the pes cavus problem of poliomyelitis origin frequently exhibits an adducted forefoot. In addition to these acquired conditions there is a distinct foot type in which marked adduction of the forefoot and inversion of the hind-foot prevails. This type of foot is designated as pes adductus. When confined in modern footgear and subjected to modern foot environment, this foot is a frequent clinical problem.

The most common form of talipes is the equino-varus deformity (Fig 114). Pes adductus is a congenital foot type of the same order as talipes equinovarus, but of such a mild degree as to usually escape notice, other than being associated with a pigeon toe or straight foot gait, until it becomes symptomatic.

The foot of the infant is very likely to exhibit considerable adduction of the forefoot Williams states, "No one has ever delivered an infant and noticed the peculiar configuration of the lower extremities without realizing that vast changes must occur before the adult type is attained." He illustrates the changing divergence of the hallux as follows: 8-week fetus, 32 0; 5-month fetus, 10.0; 9-month fetus, 8.9; newborn, 5 8; juvenile, 5 0, adult, 6.2 (G. A. Williams, '31) The adducted foot of the infant gradually yields to a straight one and should only be considered malposed when it exceeds the bounds of stability

In view of the various acquired forms of forefoot varus, each case of pes adductus should be thoroughly surveyed from a clinical standpoint in addition to the roentgen examination.

PATHO-ANATOMY

The normal alignment of the metatarso-phalangeal segments is disturbed in pes adductus Essentially, the metatarsal shafts of the first, second, third, and fourth segments assume a varus slant The fifth metatarsal usually lies practically straight, rather than in its usual valgus position, although in extreme conditions it may be varus.

The metatarso-phalangeal length-pattern ratio is materially altered The greater the adduction and hindfoot inversion, the longer the first metatarsal will appear and the more the joint line will taper toward the fifth metatarsal. This

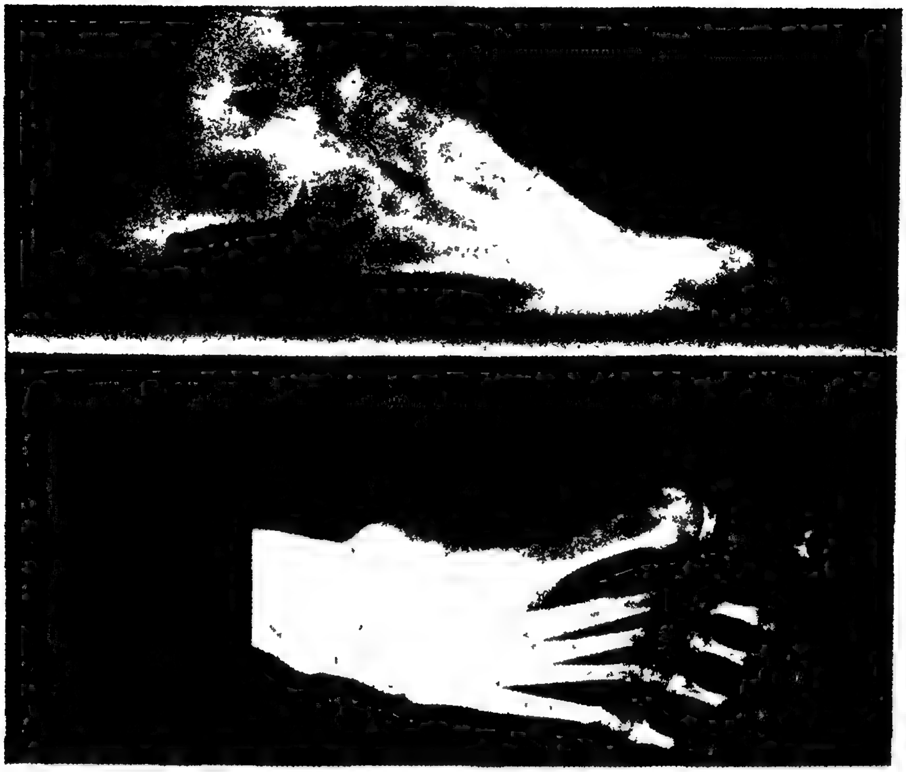


FIG 114 TALIPES VARUS—MILD EQUINUS. Medial arch segment higher than lateral arch. Observe all cuboid relationships.

is a significant finding in these cases because it accounts for excessive weight-bearing under the first metatarso-phalangeal joints. It also shows how easily the relative length patterns may be changed If the same foot were corrected to a straight alignment, an entirely different length pattern would be obtained.

It has been observed in the young subject that hallux varus frequently accompanies the general varus position of the first metatarsal. In the older person hallux valgus is likely to result from the distortion of the hallux by footgear.

Inversion of the foot originating in the hindfoot is a frequent finding in pes adductus The height of the arch may vary but the distortion pattern is similar (Fig. 115).

Radiographic Impressions

The dorso-plantar view provides the best assessment of pes adductus, although the lateral view is necessary for total appraisal of the foot problem.

The metatarsal shafts are visualized in a patho-anatomical alignment which varies in the varus degree according to the severity of the condition. The fifth metatarsal provides the key to the degree of severity for it is not easily displaced into varus unless considerable deformity is present.

The phalangeal segments vary widely in their alignment because of secondary

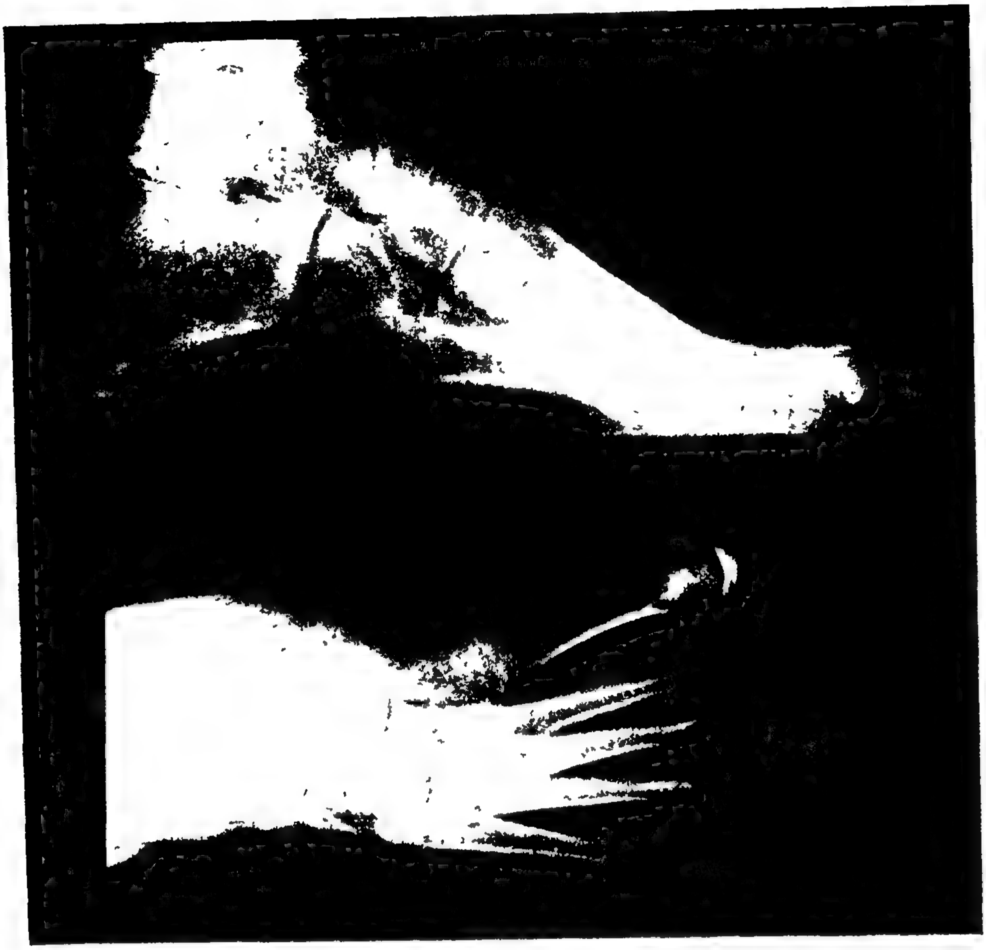


FIG. 115. PES ADDUCTUS. Inversion of hindfoot; adduction of forefoot

factors; however, the hallux usually follows the line of the first metatarsal. There is a high frequency of atavistic internal cuneiform (Fig. 116).

The relative length pattern of the metatarsal bones invariably places the first metatarsal in a position more distal than that which it would assume if the foot were straight As a consequence, the pattern is usually 1, 2, 3, 4, 5.

The radiographic appraisal of inversion begins with the relationship of the talus to the calcaneus. If the head of the talus is closely bound to such an extent that 50 per cent of the anterior process is overlapped, it is safe to assume that the foot is inverted (Fig 117). Next, the navicular should be observed to see if it overlaps the cuboid to a greater degree than is normal. The lesser cuneiforms are practically superimposed when the foot is inverted. The metatarsal bones are visualized as a tightly grouped bundle superimposed on each other and falling into a varus slant in proportion to the degree of inversion A lateral view of the inverted foot discloses that the talus sits high on the subtalor joint and that the opening of the sinus tarsi is exaggerated in size. The inner arch segment rises above the cuboid level, and the mal-aligned fifth metatarsal base is visualized in instances of abduction in high-arch cases.

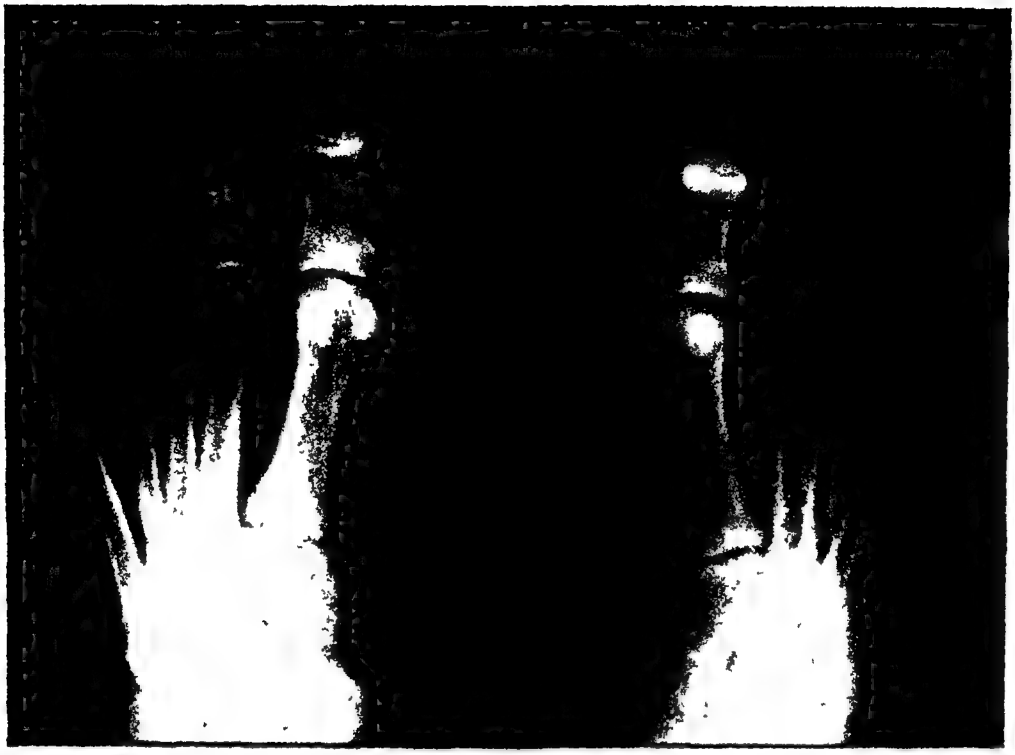


FIG 116 PES ADDUCTUS Massive medial cuneiform—atavistic in shape. Note especially flexed position of great toes. Metatarsal length pattern ratio: 1, 2, 3, 4, 5.

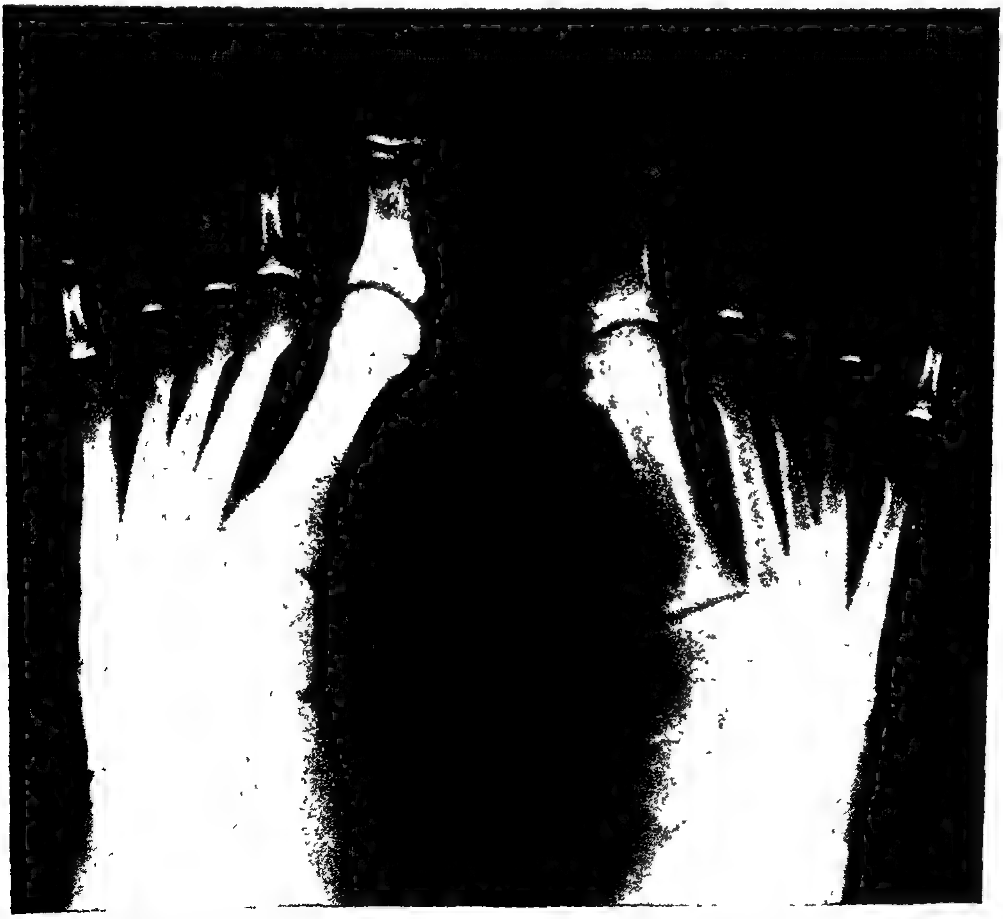
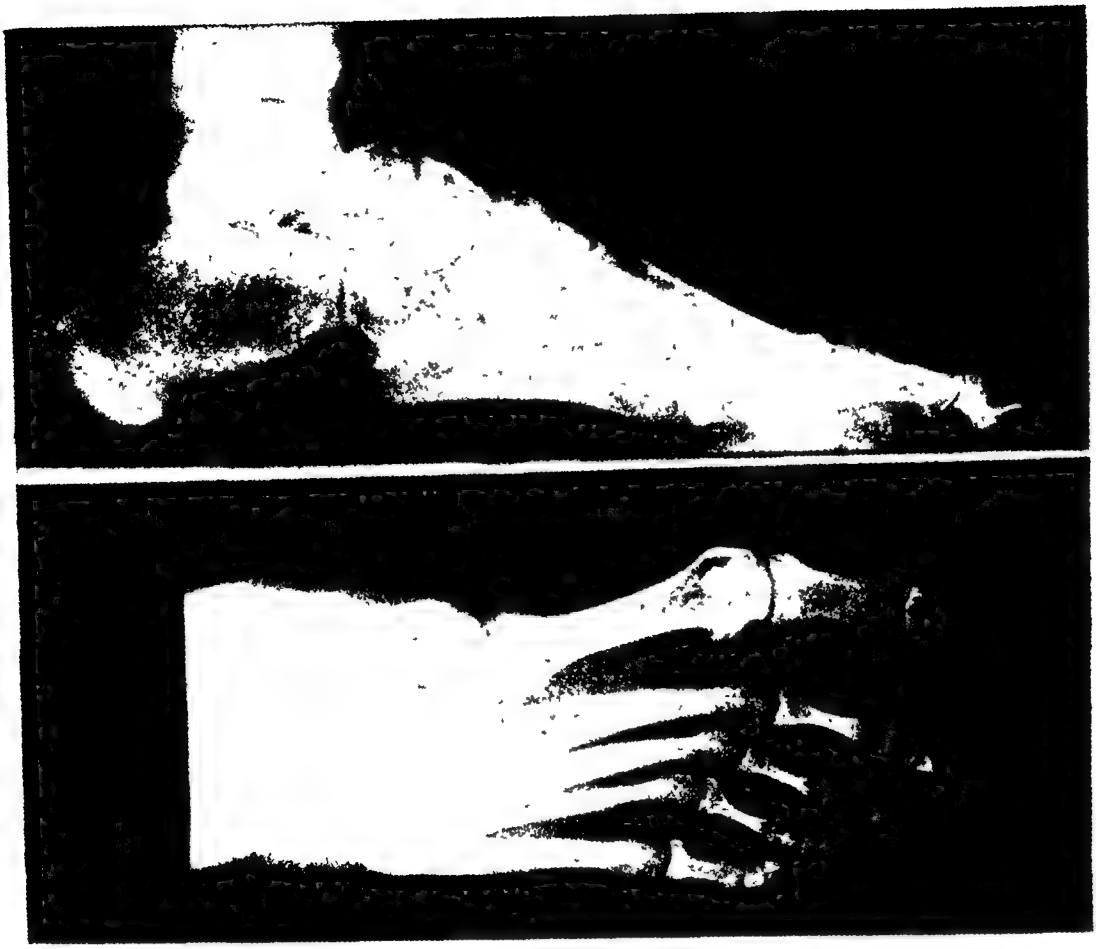


FIG 117 PES ADDUCTUS Extreme hindfoot inversion, atavistic cuneiform, extreme varus of metatarsals, Metatarsal length pattern ratio 1, 2, 3, 4, 5



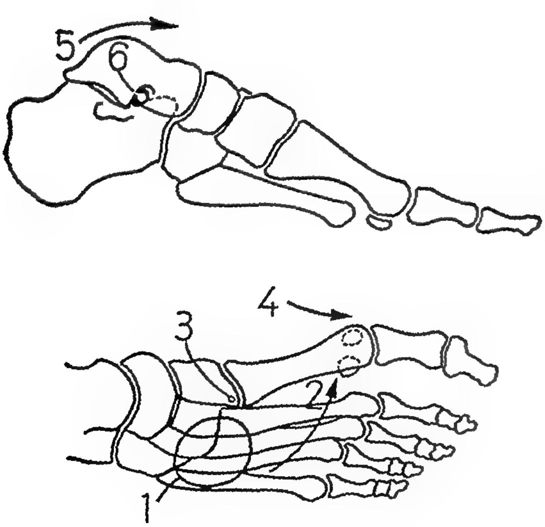


FIG 118. RADIOGRAPHIC FEATURES OF PES ADDUCTUS. *Dorso-plantar view.* (1) Inversion superimposes bases of metatarsal shafts in lateral shift (2) Note varus position of metatarsal shafts as metatarsal heads shift medially. (3) Atavistic cuneiform directs first metatarsal into varus (4) Adduction increases length ratio of first metatarsal. *Lateral view* (5) The talus is seated high on the subtalor joint. (6) Sinus tarsi is exaggerated. *Other features.* Inversion appraised by lateral overlap of calcaneus The medial arch segment rises above the cuboid level.

Radiographic Features of Pes Adductus (Fig. 118)

Dorso-plantar View

(1) The interpretation is made chiefly from the dorso-plantar view.
(2) The lesser metatarsal shafts seem to stem from a tightly grouped bundle at their bases and to assume a varus position.
(3) The first metatarsal segment assumes a varus position.
(4) An atavistic internal cuneiform is frequently the basis of the varus of the first metatarsal.
(5) The adducted position of the forefoot creates a lengthening of the first metatarsal segment in relation to the length parabola at the metatarso-phalangeal joint level.
(6) Inversion is visualized by a 50 per cent overlap of the talus over the anterior process of the calcaneus, of the navicular over the cuboid, of the cuboid over the base of the fifth metatarsal, and of the lesser cuneiforms over the cuboid, and by the superimposition of the bases of the metatarsals.

Lateral View

(1) The talus is seated high on the subtalor joint.
(2) The sinus tarsi space is exaggerated.
(3) The medial arch segment rises above the cuboid level.
(4) The mal-aligned fifth metatarsal base is high-pitched.

Clinical Considerations

The pes adductus type of foot is subject to lateral sprains of the ankle because of the inverted hindfoot and the highly specialized subtalor joint. There is a tendency for the shoes to be misshapen through the unusual stress on the lateral counter and the over-riding of the inner sole at the margin of the fifth metatarsal. Areas of excrescence develop at the base of the fifth metatarsal and sometimes under the heads of the fifth and first metatarsals due to the pivoting flow of weight through the foot during gait.

When pes adductus is discovered in a young subject, correction may be attained in mild cases by appropriate wedging at the lateral tip of the shoe sole, plus gait training. Severe cases respond to Brachman's splint. In the advanced (adult) case, all that may be achieved is accommodation to the problem and as much realignment as possible through a balanced inlay.

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Williams, G A , *Atavistic Human Foot,* Am J. Phys Anthropol , No 1, 1–5, July–September, 1931.

Brachman, P R , "Mechanical Foot Therapy," Leicht Press, Winona, Minn., 1946

Chapter VII

Metatarsal Disorders

Problems of structural defects, kinetic incompetence, and pathology of the metatarsal bones and their adjacent structures constitute metatarsal disorders. Patho-anatomy of metatarsal insufficiency which may only be visualized with any degree of accuracy through radiographic examination includes the following osseous factors: irregularity of the metatarsal length pattern, hypertrophy and atrophy of the metatarsal shafts, impingement factors, club-shaped abnormalities of the metatarsal heads, varus position of the metatarsal shaft, valgus or bowing of the metatarsal shafts, metatarso-phalangeal joint luxation, subluxation, and associated toe contraction, metatarsus latus, and pathology of the metatarso-phalangeal area.

The clinical manifestations of pain, swelling, and inflammation have frequently been bundled together under the general term of "metatarsalgia." Use of this term has led to an over-simplification of the multiple inter-related factors that are responsible for the clinical symptoms. The almost universal use of a standardized "metatarsal pad" is still another indication of the gross neglect and lack of scientific determination of metatarsal problems

The kinetics of the metatarsal area are complex, and their role in the acts of standing and locomotion must be considered in order to correlate the structural factors with metatarsal disorder.

The five metatarsal bones constitute the leverage arms over which the body weight is raised in locomotion. They represent about one-third of the total length of the foot and thus form a substantial span that must be controlled as the body is propelled forward. The distal ends of the metatarsals terminate in a rounded head that enters into a ginglymus joint with the phalangeal segment. The plantar area of the lesser metatarsal heads, which is designed to receive weight, is relatively small and condylar. The adjacent toes share the weight load. The first metatarsal head articulates with two sesamoid bones which also share the weight distribution. Each metatarsal carries a proportionate amount of weight, according to the specific factors involved in each case. We may infer from the research of Morton and others that in the static attitude a fairly normal ratio consists of two units to the first metatarsal and one unit to each of the lesser metatarsals. Even this well-developed ratio fails to be absolute when we consider the amount of weight carried by the fifth metatarsal in a highly arched foot as compared to that carried by a low arch foot where more of the shaft would participate in the work load.

It is generally agreed by Henenfeld, Lewis, Morton, and Sansone that in locomotion the adjustment of the forefoot to the unevenness of walking surface is achieved by the deployment of the metatarsal segments. The intrinsic muscles of the foot contribute greatly to this adaptation. There is, however, disagreement concerning the mode of weight distribution and the relative importance of each metatarsal in sharing the weight transfer during locomotion. Morton has described the flow of weight through the foot under normal circumstances as following the axis of balance between the second and third metatarsal heads and swerving medially upon the heads of the first and second metatarsals as soon as the leverage phase of action begins. This flow pattern suggests that the weight follows through in an "up and over" direction with excessive weight distributed to the longest metatarsal bone. Henenfeld shows the flow pattern as following through the third metatarsal, which he terms "the line of functional weight transmission"; and, as the foot is used in leverage to initiate gait, the second metatarsal, which is the longest in a normal foot, will act as a fulcrum. The weight will then pivot in either a medial or a lateral direction, depending mainly upon the condition confronting the foot at the particular time. He lists these conditions as in-toeing and out-toeing, change in body direction, and uneven, slanting, or sloping surfaces, and lateral shifts of body weight.

Civilization places extreme demands upon the forefoot. These demands complicate weight flow and distribution during locomotion and standing. The unshod native foot, walking on resilient surfaces such as turf, sand, or grassland, is able to utilize the foot structure and toes at their highest functional efficiency. When applied to the primitive use of the foot, the arguments of some authors, who say that the long toe flexors are neutral in the act of progressive take-off, seem untenable. Even the simple experiment of walking on a sandy beach will offer ample evidence that the flexors do become active in raising the body weight and adding propulsive purchase during forward progression. The only justification for considering the flexors neutral would be their inability to act due to an unyielding surface or the splinting effect of shoes.

ORTHODYNAMIC WEIGHT DISTRIBUTION

Through the use of orthodynamic weight-distribution, foot-imprint radiographs (see Chap XIX for technique), we have concluded that both pivotal action and "up and over" leverage are combined in the scheme of weight-force transfer These show an ink imprint of the foot passing through the act of taking a step simultaneously recorded on a radiograph of the foot Of great importance is the fact that an extensive imprint of the great toe indicates its participation and, to a lesser extent, the participation of the lesser toes in weight transfer which in many instances overbalances length parabola and other factors heretofore considered The gradation of the amount of weight distributed to various areas on the imprint provides specific evidence as to which metatarsal head performs the greatest work and what is the extent of toe participation

Every case of metatarsal insufficiency should be correlated with weight-dis-

tribution foot-imprint radiographs. The interpretation of this density-controlled imprint will require a complete evaluation of the structural factors plus the functional ability of the total foot, and especially of the strength of the toes. From a strictly objective radiographic interpretation, the normal foot imprint should show weight impress equally distributed under the following: each meta-tarso-phalangeal joint, the sesamoids of the great toe joint, the inter-phalangeal joint of the great toe, and the distal ends of each small toe.

Instances of an extremely short first metatarsal demonstrating the imprint of excessive weight force carried by the third metatarsal instead of the longer second metatarsal have been recorded (Fig. 119). This contradicts Morton's theory and also contradicts to some degree the theory of medial pivotal action that might be expected from Henenfeld's concept. An extensive imprint of the great toes in these cases indicates that strong action of the flexor hallucis longus overpowered the foot into lateral pivotal action.

Elftman has performed a remarkable study of the distribution of pressure in the human foot. This study consists of a motion picture record of weight distribution from moment-to-moment of gait as produced on a rubber-pyramid mat barograph and reflected in a manner to coincide with the lateral picture of the foot. He concludes that "when the ball of the foot leaves the ground, the toes alone exert pressure." Furthermore, Elftman observes, "A line joining the greatest pressure in the ball of the foot tends to remain parallel to the direction of progression." Schwartz, Heath, Misick, and Wright, through their electrobasograph, have established an elaborate method of recording gait by electrical contacts fastened to the foot. These record every moment of weight-distribution duration Motion picture studies recorded by a carriage that moves synchronously with the advancing step in gait further elaborate the study. The areas under study consist of the heel, fifth metatarsal, and great toe. Again, this sequence illustrates the importance of the great toe in the progressive step.

Jones advances another factor that must be reckoned with in reference to

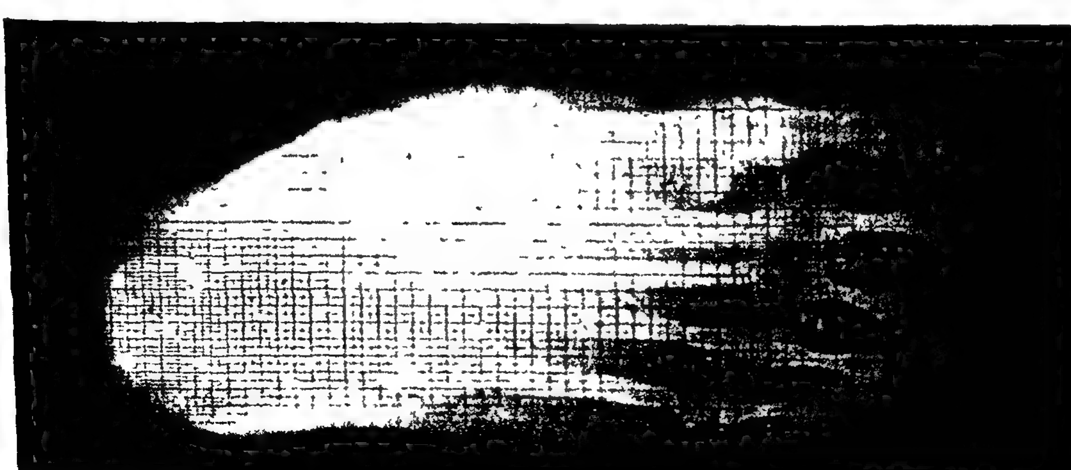

FIG 119 ORTHODYNAMIC WEIGHT-DISTRIBUTION FOOT-IMPRINT RADIOGRAPH Short first metatarsal foot type Excessive weight-force upon third metatarsal head, medial sesamoid bone, and great toe

his study of 50 subjects in an article entitled The Functional Significance of the Declination of the Axis of the Human Talocalcaneonavicular Joint. He claims that rotational torque in the tibia greatly affects the ratio of weight distribution among the five metatarsal heads comprising the ball of the foot. Lateral rotational torque in the tibia increases the proportion of weight borne by the lateral four metatarsals, whereas medial torque increases the proportion of weight borne by the first metatarsal. (R. L. Jones, '44)

If we should like to gain mathematical perfection, we might very well develop extremely technical appraisals according to each precise conditioning effect. However, in a practical sense we must accept certain factors as the predominant ones and do our best to apply this knowledge to each case. The imprint radiograph, which can be performed by a simple office technique, provides a practical record that may be easily interpreted.

Radiographic Impressions

The normal features of the metatarsal area have been extensively discussed in the chapter concerning the normal foot. To recapitulate, the relative length pattern is 2, 1, 3, 4, 5; the weight-distribution ratio is 2:1:1:1:1; and the average parabola of the metatarso-phalangeal joints is 142.5° (Fig. 36). Collateral data will be supplied as the roentgen considerations of the various features contributing to metatarsal disorders are made.

IRREGULARITY OF THE METATARSAL LENGTH PATTERN

Various investigators report a variety of relative length patterns as the normal standard. Harris and Beath measure the relative length of the first and second metatarsals by describing an arc through the distal extremes of the first and second metatarsals from a point at the center of the posterior aspect of the calcaneus. They compare their findings with the relative length obtained by Morton's method, in which the second metatarsal is bisected and a line drawn perpendicular from the distal end of the second metatarsal toward and through the first metatarsal They claim that Morton's method would be affected by varus and valgus of the forefoot to such an extent that unreliable shortness would be obtained. Of 7,177 cases that were measured by Harris and Beath, 1,596 have equal length; 2,888 have short first metatarsals; and only 2,693 have long first metatarsals The second was predominantly the longest metatarsal. Also Plaster concurs with the above as a result of an extensive measurement series.

In a series of 281 cases (the combined work of Gamble and Schuster), the angle formed by the center of the distal end of the first metatarsal, the second metatarsal, and the fifth metatarsal was established at a mean 142.5°. By relating this angle to the first metatarsal, which we have standardized as 2 mm shorter than the second metatarsal, the fifth metatarsal will be approximately 32 mm shorter than the second metatarsal, and the third and fourth will take their places along the line subtended from the second to the fifth This average length pattern of 2, 1, 3, 4, 5, at a parabola angle of 142 5° presents a very efficient hinge joint for the combined metatarso-phalangeal joints, with the result

that weight transfer is achieved without excess on any particular metatarsal head—providing that the supplemental action of all the toes contributes to normal purchase. Under these circumstances pivotal action will be minimized.

In the same series of 281 cases, the extremes of the parabola are ranged from 120° to 160°. It may be readily seen that as flat a curve as 160° presents almost uniform length of all the metatarsal shafts. Thus weight-transfer problems in a case of this kind would be reduced to an absolute minimum, whereas the acute curve of 120° would surely increase the hazards.

It is difficult to offer a simple, relative measurement of critical, metatarsal length discrepancy that is highly accurate. There are several ways to estimate deficiencies. The normal pattern follows a smooth parabola from the first metatarsal to the zenith at the second metatarsal head and then tapers to the fifth with the intermediary heads meeting this line. A calculating study of a radiograph will often reveal a metatarsal head that exceeds the parabola, or the converse, where it fails to reach the parabola line. To check specifically the length of the second metatarsal a ruler may be held across the distal end of the first and third metatarsals on a dorso-plantar radiograph, and, if the second metatarsal head extends more than 4 mm., it may be considered an excessively long member.

Measurement of the length of each metatarsal in one foot and comparison with the measurements for each metatarsal of the other foot provides a comparative assessment. This might be of value when a unilateral problem is plainly evident. In every instance of this type of measurement there must be absolute standardization of the technique employed in producing the radiographs so that geometric distortion will not occur.

A very important matter is the alteration of the metatarsal joint which is the result of mid-tarsal fault with subsequent elongation of the medial longitudinal arch segment. The flexibility of this segment will permit the first metatarsal to be extended beyond the second metatarsal joint line, and thus a new ratio of metatarsal length will be established. This acquired situation often accounts for a long first metatarsal with a fellow, hypertrophied second metatarsal—a situation which otherwise might seem incongruous. In the last analysis, the situations affecting the metatarsal function will conform to the final pattern, even though the parabola may be altered from the natural pattern because of arch fault and elongation.

Another altering factor is the matter of adduction of the forefoot which tends to elongate the length of the first metatarsal as compared to that of the second. Hallux valgus is another factor that changes the pattern and in this connection any weakness of the metatarsal segment from the basal articulation will necessarily create a transfer of impost to adjacent metatarsals. Rotation of the metatarsal on its long axis creates greater pressure on one condyle and sesamoid of the metatarsal head

The prime objective in arriving at a standard relative-length pattern is to be able to detect discrepancies easily. If one or more of the metatarsals exceeds the normal length pattern, they are suspected of carrying excessive weight transfer or of diverting the weight transfer in pivotal action.

Figs. 120–133. Irregularity of the Metatarsal Length Pattern

Fig 120 Normal Metatarsal Length Pattern.

Fig. 121. Relatively Uniform Length Pattern.

The metatarsals that fall short of the normal length pattern are usually not of direct significance, except for their effect on pivotal action Their deficiency is a side issue compared with the adjacent members that would be long under the circumstances

Superficial skin excrescences are provoked by excessive friction and pressure It is common knowledge that excessive length of the metatarsal bones is responsible for clavus under the offending members, although, of course, there are other contributory factors such as contracted calf muscles which hold the metatarsal heads in ground contact without yield in the advancing step, footgear of the thin-soled, high-heeled variety, hard unyielding pavement walking surfaces, insufficient soft tissue under the metatarsal heads, and fibrous adhesions

It is axiomatic that the long metatarsal provokes symptoms, whereas short members contribute to the direction of pivotal action, unless over-powered by toe action.

FIG 122 Long First Metatarsal.

FIG 123. Long First and Second Metatarsals.

The irregularities commonly visualized and their clinical problems may be correlated as follows:

Long First Metatarsal. Concentric excrescence beneath the sesamoid carrying the greatest impost.

Long First and Second Metatarsals. An extended excrescence under the sesamoids and metatarsal heads

Long Second Metatarsal The excrescence concentrated under the head of the second metatarsal.

Long Second and Third Metatarsals. The excrescence extended across the ball of the foot under the second and third metatarsal heads.

Long Third Metatarsal. An excrescence under the third metatarsal head.

Long Fourth Metatarsal. Occasionally an excrescence under the fourth metatarsal head but more often a problem of heloma on the end of the fourth toe resulting from the excessive length of this segment and the increased demand on toe purchase.

Short First Metatarsal This encourages medial pivotal action. If the rest of the metatarsal length pattern is normal, little effect on the foot is observed

Figs. 120–133. Irregularity of the Metatarsal Length Pattern

Fig. 120 Normal Metatarsal Length Pattern.

Fig. 121. Relatively Uniform Length Pattern.

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FIG 126 Long Third Metatarsal.

FIG. 127. Long Fourth Metatarsal (Note toe position).

129, 130). The cortical walls are increased in thickness, and the entire volume of the bone is heavier. In normal cases the three middle metatarsals are of approximately the same volume, or width, as observed in the dorso-plantar radiograph. It is a simple matter to assess a hypertrophied member by comparison with adjacent members In cases of two metatarsals bearing excess weight distribution both members will be hypertrophied

The converse is true when atrophy results from a metatarsal not carrying its normal share of work load Instances of atrophy are not numerous, as it is rare that a single metatarsal abstains from substantial function A first metatarsal, even though short, still carries enough weight force to maintain nearly normal volume, except in cases of excessive shortness and weakness of the peroneus longus, which tends further to lessen the function of this member as a leverage arm Short members couched between long members, such as the fourth metatarsal, are likely to be diminutive

Cases of hypertrophy of the second metatarsal, in which adjacent members are of equal length, are sometimes visualized. In these instances it is wise to check for mid-tarsal fault with subsequent foot elongation The hypertrophy may have been acquired during the early life of the individual and the elongation begun only in the last decade so that the radiographic appearance would not corroborate the clinical concept.

FIG. 124. Long Second Metatarsal

FIG 125 Long Second and Third Metatarsals.

Short Fourth Metatarsal Non-symptomatic in the metatarsal area but the adjacent digit is often contracted and presents a problem because of shoe pressure

Uniform Length of all Metatarsals. This pattern is never completely uniform but is approximate. Impingement problems are presented when this type of foot is shod in a tightly fitted shoe

Short Third and Fourth Metatarsals This unusual pattern has been observed in five instances by this writer and illustrations of three of the cases are given No opinion is ventured concerning the basic etiology except to consider the cases as problems of developmental defect The clinical problem consists of excrescence under the long members, general foot imbalance, and toe contraction.

Other patterns Instances of other length patterns have been reported, but those given here are most commonly encountered (Figs 120–133)

HYPERTROPHY AND ATROPHY OF THE METATARSAL BONE

One of the most dramatic demonstrations of Wolff's law of functional adaptation in bone is shown in the hypertrophy of the shaft in instances of an excessively long metatarsal bone that takes the weight-force impost during gait (Figs.

Fig. 126 Long Third Metatarsal.

Fig 127. Long Fourth Metatarsal (Note toe position).

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Fig 128 Short First Metatarsal. Arrested growth due to epiphyseal injury. Lesser metatarsals follow a normal pattern, consequently, this is a useful foot

Fig 129. Short First Metatarsal Note hypertrophy of second metatarsal shaft as compared to atrophy of third metatarsal shaft.

IMPINGEMENT FACTORS (Figs. 134, 135)

Impingement is, in fact, a juxtaposition of two metatarsal heads, and it may be assumed that there is a squeezing of tissues between them as the foot is deployed in the many demands of progressive gait Ample clinical evidence is elicited by the pain of inter-metatarsal bursitis, and radiographic evidence identifies the cause of this problem. No doubt nerve impingement with its attendant symptoms is another factor. This is, of course, also a factor in some cases of Morton's neuralgia

In visualizing the metatarsal area of a dorso-plantar radiograph, the two metatarsal heads often seem to be touching. This might lead to the erroneous impression that the bones were actually making bone-to-bone contact. However, this has not been demonstrated on anatomical specimens, there being sufficient flexibility and soft-tissue to preclude such a pathologic disaster. The term "impingement" must be used carefully, for the position recorded on the dorso-plantar radiograph is strictly a feature of one-plane roentgen projection and could mean merely that a raised metatarsal shaft overlays an adjacent metatarsal head in spatial relationship.

When metatarsal heads assume a position of impingement it is wise to check the foot clinically to see if ligamentous restriction is responsible for their proximity. By palpably moving the adjacent metatarsal heads in such instances one may discern a restriction which is very immobile. This is, no doubt, a soft-tissue anomaly.

Impingement is not restricted to the metatarsal heads. The basal articulations of the phalanges must be considered as integral parts of the derangement and, consequently, as contributory to the painful consequences.

Juxtaposition is common in metatarsal bones of uniform length and becomes a clinical problem when tight shoes are worn.

ABNORMALITIES OF THE SHAPE OF METATARSAL HEADS

Heavy-boned individuals sometimes encounter problems due to the excessive shape of the head of the metatarsal bones as a result of their general skeletal type. These large heads, if of or near uniform length pattern, create a crowding situation with all of the impingement problems akin to this region. If properly shod there is no reason why this foot type should be a handicap to anyone. It is merely subject to the hazards of modern foot environment (Fig. 136).

VARUS POSITION OF THE METATARSAL BONES

As a direct result of foot collapse, the altered alignment of the medial and lateral arch segments creates varus positions and rotations on the long axis of the third and fourth metatarsal shafts, thus creating impingement of the second and third metatarsal heads. The distal manifestation of this problem takes the form of spreading of the second and third toes as the third toe falls into valgus position from its varus metatarsal member. As the foot elongates, cognizance must be taken of the fact that the extensor tendons attached to the toes do not elongate in like proportion and, therefore, the toes are drawn back At the same time, the location of the dorsal interossei stabilizes the second toe by insertions on both sides of the base and diverts the third toe into valgus because of the single insertion on the lateral side of the base of the phalanx. In addition, torsion of the third cuneiform contributes to rotation and varus of the third metatarsal. This syndrome is of great importance in evaluation of metatarsal symptoms and is a valid reason for holding every case of longitudinal arch fault suspect of creating metatarsal disorder (Fig 137).

The adducted foot presents metatarsal shafts aligned in varus position and contributes to the following clinical problems. Extreme adduction may create a metatarsal length pattern in which the arc is exceedingly acute from the first to the fifth A pigeon-toed gait may create excessive pressure under the fifth metatarsal head with over-riding of the sole and subsequent excrescence formation (Fig. 138).

VALGUS POSITION OF THE METATARSAL BONES

In a longitudinal arch disorder the fifth metatarsal sometimes assumes a valgus position when it rotates into complete collapse. In the severely abducted foot, the first metatarsal may rotate into a valgus position and the lesser metatarsals may fall into line (Fig 139).

Figs. 131–133. A series of three unusual cases with short third and fourth metatarsals

FIG 130. Short fourth Metatarsal
FIG. 131. Short third and fourth Metatarsals
FIG. 132 Short third and fourth Metatarsals (Courtesy of Dr. L. A. Walsh).
FIG. 133. Short third and fourth Metatarsals (Courtesy of Dr. S. Max).

← FIG 130

FIG 131
↓

Fig. 132 →

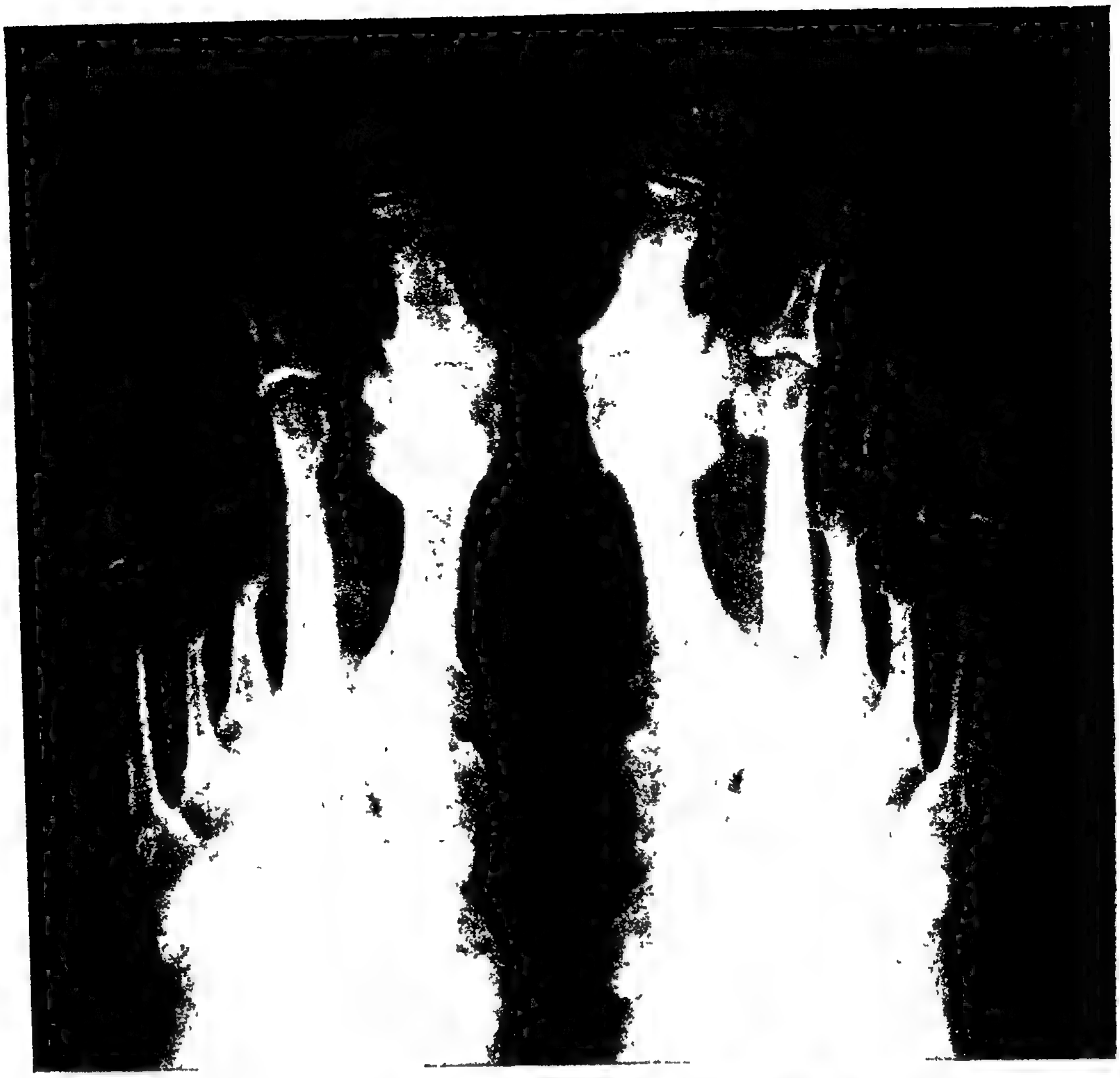

Fig. 133 ↓

FIG 134 METATARSAL IMPINGEMENT FACTORS. Juxtaposition of second and third metatarsal heads—secondary to mid-tarsal fault.

Morton has drawn attention to a "medial convexity" of the metatarsal shafts, which he claims is characteristic when the foot follows a habitual outflare gait. In our opinion this valgus bowing of the metatarsal shafts is not a common occurrence, and other contributing factors are needed to bring about the altered

FIG 135. METATARSAL IMPINGEMENT FACTORS. Juxtaposition of second and third metatarsal heads—secondary to inverted adducted foot.

architecture. Otherwise we would see many many cases of bowed metatarsal shafts from outflare-gait feet. Lack of normal toe purchase to assist in propulsion may be a contributing factor, thereby making metatarsal head push-off the complete recipient of weight force.

FIG 134. METATARSAL IMPINGEMENT FACTORS. Juxtaposition of second and third metatarsal heads—secondary to mid-tarsal fault

Morton has drawn attention to a "medial convexity" of the metatarsal shafts, which he claims is characteristic when the foot follows a habitual outflare gait In our opinion this valgus bowing of the metatarsal shafts is not a common occurrence, and other contributing factors are needed to bring about the altered

FIG 138 VARUS POSITION OF THE METATARSAL BONES Varus displacement of second, third, and fourth metatarsal shafts, with juxtaposition of metatarsal heads, alteration of length pattern, and lateral deviation of toes—secondary to adducted foot.

FIG. 139. VALGUS BOWING OF THE METATARSAL BONES. Compensatory adduction of forefoot.

severe subluxation or luxation, the joint is disorganized so that the dorso-plantar view demonstrates an image of the phalanx base superimposed over the head of the metatarsal

Side-to-side luxation occurs as a feature of severe hallux valgus in the first metatarso-phalangeal articulation. Dorso-plantar subluxations of the second metatarso-phalangeal joint occur when the second toe is displaced by an underlapping hallux in cases of severe hallux valgus. Toes may be forced into subluxation by acute or incipient trauma.

Simple subluxations develop as a result of contractions of the extensor digitorum longus which are the result of habitually wearing incorrect shoes with high heels. Complicated subluxations occur in the Shaeffer foot-t

FIG 136 CLUB-SHAPE ABNORMALITIES OF THE METATARSAL HEADS. Impingement through juxtaposition of uniform metatarsal length Note hammer toe deformity of second toe

FIG 137. VARUS POSITION OF THE METATARSAL BONES Mild varus displacement of second and third metatarsal shafts, with juxtaposition of metatarsal heads, and lateral deviation of third toe—secondary to medium mid-tarsal fault, and contraction of toe extensor tendons

METATARSO-PHALANGEAL JOINT LUXATION, SUBLUXATION AND ASSOCIATED TOE CONTRACTIONS (Figs. 140–143)

Perhaps one of the most common symptom-producing problems of metatarsal disorder consists of joint disorganization of varying degrees with associated toe contraction. There is a variety of causes for these situations, but in practically every instance painful metatarsal bursitis, nerve impingement, tissue inflammation, and over-lying skin excrescences are present in some degree.

Radiographically the subluxation is visualized as a diminution of the joint space between the metatarsal head and the base of the proximal phalanx. In

Fig 141. Metatarso-phalangeal Joint Luxation. Lateral deviation of second toe—secondary to Hallux Valgus

Fig 142. Metatarso-phalangeal Subluxations Second and third toes displaced due to contractions of extensors—no Hallux Valgus

able and the widest shoe will not seem to accommodate the extreme spread of the forefoot Several surgical procedures for artificially binding the metatarsal bones in closer proximity have been developed (Fig 144)

PATHOLOGY OF THE METATARSO-PHALANGEAL AREA

The destructive ravages of various forms of arthritis create disorder of the metatarso-phalangeal region As explained under subluxations, rheumatoid arthritis has a special predilection for attacking the metatarso-phalangeal joints. Furthermore, resorption and destruction occur to such a degree in advanced cases that it is impossible for the joint to maintain organization Degenerative osteo-arthritis creates problems of restricted joint motion through the development of calcifications at the metatarso-phalangeal joint margins. Infectious arthritis restricts normal physiology of the joint through an acute inflammatory process and effusion Gouty arthritis, through its subtle substitution of urate

FIG 140 METATARSO-PHALANGEAL JOINT SUBLUXATION. Complete subluxation of second metatarso-phalangeal joint Secondary to trauma Note base of second metatarsal Hallux Valgus does not complicate this case

cavus, postpolio deformity accounts for subluxations at the metatarso-phalangeal joint.

A unique and pathognomonic lateral or fibular deviation occurs in rheumatoid arthritis subluxations due to incompetence of the short toe flexors, plantar interossei, and lumbricales All of the metatarso-phalangeal joints may be involved

METATARSUS LATUS

Because of laxity of the transverse metatarsal ligament and associated musculature, a condition is occasionally found in which the metatarsal segments are subject to extreme splaying The flaccidity of this foot type is almost unbeliev-

Figs. 145–152. Pathology of the Metatarso-Phalangeal Area

FIG 145. RHEUMATOID ARTHRITIS. Fibular deviation of all toes with joint disorganization A pathognomic pattern.

weight-bearing areas under the metatarsal heads which are so cleanly reduced to shaftlike ends (Fig 151).

Osteochondritis of the metatarsal heads is common, with Frieberg's infraction of the second metatarsal head most frequently encountered (Fig. 152). However, every metatarsal head may undergo the same sequence of accelerated and bizarre development, except the first, in which the epiphysis is basal. Osteomyelitis is responsible for extreme metatarso-phalangeal involvements. Malignancy involves metatarsal members through direct osteogenic types and through secondary involvement from synovioma.

The vital need for a radiograph of every case of clinical metatarsal insufficiency should be amply demonstrated by this discussion of the types of bone pathology that may be lurking unseen until disclosed on the radiograph.

FIG 143 METATARSO-PHALANGEAL SUBLUXATIONS All lesser toes involved as a result of post-poliomyelitis contractions

FIG 144. METATARSUS LATUS Laxity of transverse metatarsal ligaments and general foot flaccidity.

salts for normal bone mineralization gradually weakens the structure of the metatarsal heads and articulating phalanges until the area is incompetent In addition, exquisite pain is pathognomonic of this disease Minimal traumatic arthritis in its insidious manner creates depositions of osseum so that joint margins lose their smooth function and become inefficient and painful (Figs 145–150).

The neurotrophic diseases seem to select the metatarso-phalangeal joint as a site of preference Resorption of metatarsal heads, in cases of syringomelia, leprosy, and other nonspecific cord lesions, devastates any possible joint organization and usually results in dorsal subluxations of the toes and in painful

FIG. 149. Gouty Arthritis. In advanced state presents a weakened and painful structure.

FIG 150. Minimal Traumatic Arthritis Creates severe mechanical problems

Fig 146 Advanced Rheumatoid Arthritis Complete disorganization of metatarso-phalangeal joints

Fig 147. Degenerative Osteo-arthritis. Restricts joint motion by altered joint constituents

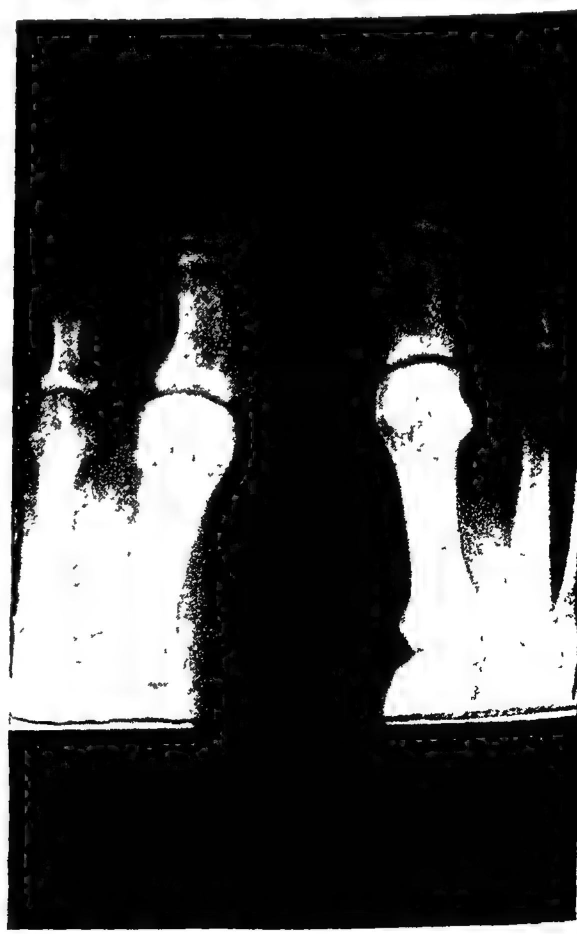

Fig 148. Acute Infectious Arthritis Restricts joint motion through pain and effusion.

FIG. 151. Neurotrophic Resorption of Metatarso-phalangeal Constituents.

FIG. 152. Frieberg's Infraction of Second Metatarsal Head (Courtesy of Dr. R. Oestreich).

(10) Radical deviation of the combined metatarso-phalangeal joint parabola is the clue to the direction of pivotal action of the foot. It usually follows the direction of the acute angulation of the parabola

(11) Hypertrophy of a metatarsal shaft indicates that it has at some time performed an excessive function. Foot structure changes, and it is possible, although exceptional, to find a hypertrophied member in an altered position where it no longer performs excessive function but merely indicates by its hypertrophy that it did so in the past

(12) Atrophy of a metatarsal shaft indicates that it has not participated in work load

(13) Impingement factors exemplify some change in the total structure of the foot, and normal alignment may only be achieved through total rehabilitation of the foot structure and gait. Simple devices such as spot metatarsal lifts under the specific metatarsal involved may offer some relief but will fall short of effecting complete correction.

Radiographic Features of Metatarsal Disorders

(1) Irregularity of the metatarsal length pattern
(2) Hypertrophy and atrophy of the metatarsal bone.
(3) Impingement factors.
(4) Abnormalities of the shape of metatarsal heads
(5) Varus position of the metatarsal bones.
(6) Valgus position of the metatarsal bones.
(7) Metatarso–phalangeal joint luxation, subluxation and associated toe contractions
(8) Metatarsus latus.
(9) Pathology of the metatarso–phalangeal area.

Clinical Consideration of Metatarsal Disorders

(1) Although most of the basic information concerning a specific metatarsal problem is to be gained from the dorso-plantar view, additional views may be needed to gain complete visualization of a lesion.

(2) The total foot must be radiographed in order to make a comprehensive diagnosis of metatarsal disorder. The elongation of the foot that takes place in many cases of mid-tarsal fault forces the first metatarsal forward thus altering the length pattern Varus position of the third metatarsal shaft is another example of the total foot alignment creating the metatarsal problem.

(3) The radiographic findings should be correlated with kinetic factors of gait and weight impost. Other clinical manifestations such as skin excrescences should also be considered

(4) Orthodynamic weight-distribution foot-imprint radiographs are simple to produce and are of inestimable value in studying both the participation of the toes in take-off and all of the other weight-distribution areas

(5) The torque of the tibia should be studied as a factor in directing the weight distribution The torque varies with mid-tarsal fault

(6) Muscle groups should be evaluated to determine imbalance such as, for example, a contracted calf group as a factor in creating unyielding flexion at the ankle, thereby causing excessive pressure in the metatarso-phalangeal area

(7) The radiographic study should reveal the structural factors involved in the case This information should be used to decide the type of accommodative appliance to be used and the plan for rehabilitation treatment.

(8) Irregularity of the metatarsal length pattern requires compensation The leverage arm of the short member or members is extended by a platform placed under the head of the deficient member Appliances designed in this manner may be made of felt until the proper correction is obtained and later duplicated in Celastic or leather.

(9) Although a short metatarsal may require an extended platform, the total foot situation must be considered and all the modifications necessary for the total foot problem should be incorporated in the same appliance.

Surgical reconstruction of the intractable arthritic case of metatarsal insufficiency is frequently the only feasible way of overcoming all the associated problems. Resection of the metatarsal heads involved, and surgical straightening of the toe into an improved position is the usual procedure.

The use of molded shoes in which a crest is incorporated under the toes creates a special foot environment that is conducive to good toe action, thus relieving metatarsal head pressure. The toes are held in a position of flexural contact which is better than the uninhibited flat surface provided by the inner sole of the conventional shoe. The molded shoe completely encloses the foot and toes; thus, accommodation on an individual basis may be accomplished. The molded shoe does not achieve the toe action that is achieved barefoot on sand, since the plantar mold is of rigid and unyielding material. The combination of better foot accommodation and opportunity for intrinsic muscle action provided by the molded shoe should help to sublimate metatarsal disorder. The heavy sole that is commonly applied offers a further advantage in protecting the foot from the harshness and irregularity of present-day walking surfaces.

(18) Metatarsus latus involves an idiopathic flaccidity of the foot that is difficult to control except through surgical procedures that provide an artificial metatarsal binding by threading a tendon through holes in the shafts of the metatarsals to achieve the reconstruction.

(19) When pathology involves the metatarso-phalangeal elements and ambulation is possible, there is some value to accommodative footgear and devices to disperse weight forces from the metatarso-phalangeal area posteriorly to the shafts and tarsal area. Metatarsal bars on the outside of the shoes are used, and soft sponge material is utilized in specific padding under the metatarso-phalangeal joints.

(20) Problems of insufficient adipose tissue under the metatarso-phalangeal area require artificial padding to supplement the deficiency.

(21) Neuritis associated with periphero-vascular disease, diabetes, and other diseases should be considered when evaluating metatarsal insufficiency after the radiographic study has been completed.

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(14) Club-shaped abnormalities need little more than adequate accommodation in the shoe.

(15) Varus position of the metatarsal bones due to pes adductus must be treated accordingly When it is because of internal derangement of the foot caused by foot collapse the usual rehabilitation for that condition must be instituted.

(16) Valgus bowing of the metatarsal bones is rare, and a specific evaluation of the problem must be made to correct it.

(17) Metatarso-phalangeal joint subluxation and the associated toe contractions present the most common manifestation of metatarsal disorder and, in extreme cases, the most devastating problem found in this area.

The mild forms of subluxation are provoked by the habitual use of high-heeled shoes, which disturbs muscle balance and weight distribution. Use of proper footgear during the majority of the day is essential in these cases In addition, there must be comprehensive muscle rehabilitation through stretching, electrical contractile currents, and exercise.

Conventional metatarsal pads that lift the middle three metatarsal shafts have very little effect on reducing subluxed or contracted toes. Some small measure of assistance might be gained by a very high pad that would actually help to raise the shafts and force an altered position of the toe However, this practice is fraught with the danger of causing atrophy of plantar soft tissue Other specific methods should replace this outdated approach

Advanced forms of subluxation with toe contraction require orthodigital devices for their correction Felt or plastic crests placed underneath the toes so that the toe flexing muscles may be encouraged to make purchase are very effective in overcoming the contracted extensor muscles and permitting the subluxation to be reduced Even the severe cases due to rheumatoid arthritis are benefited by the use of purchase crests beneath the toes. Although it does not materially reduce the subluxation, the short toe flexors, plantar interossei, and lumbricales are given an opportunity to act, which essentially improves the balance and stability of the foot. In the arthritic foot, the long toe flexors which are attached to the distal phalanges retain power and, as a result of the disorganization of the joint, act in a detrimental manner unless neutralized by the purchase crest

As a result of the mobility of a metatarsal segment, the contraction of a toe is followed by a downward displacement of the metatarsal head, which is prominently abused in walking because the toe no longer shares the take-off burden. Prominent metatarsal heads create secondary skin excrescence problems due to friction and pressure.

The problem of accommodation of severely dislocated metatarso-phalangeal joints may be resolved by pocketing the depressed metatarsal head or heads in an appliance Molded inlays are satisfactory in these cases, provided that adequate modification is insured When joint destruction has taken place and in cases where other measures fail, the metatarsal bar attached to the sole of the shoe transfers weight across the shafts of all of the metatarsal bones and creates a fulcrum for the take-off in walking on an unaffected area.

Chapter VIII

Orthodigital Problems

Orthodigita has developed throughout the history of chiropody through the contributions of many of its members. Runting and Charlesworth of England made many early contributions in the form of "toe prop pads," which served to straighten toes. Budin defined the word "orthodigita" in connection with splinting and traction devices, thus giving this special field of orthopedic work a designation. Budin, the pioneer investigator in the field of orthodigita, states, "orthodigita is concerned with the prevention, amelioration, and correction by nonsurgical means of toe deformities and mal-alignments, as well as the resultant lesions and other painful effects." Although, as Budin has said, orthodigita is primarily concerned with nonsurgical correction, the irretrievable cases and complications may require intervention. We deal, however, with the simon-pure science of orthodigita and with the problems that do not respond to such techniques by surgery. It has been our experience that radiographs have been of invaluable service, both in identifying orthodigital problems and in assisting in the evaluation of progress in the management of these cases.

Just as the dental profession has, for many years, been engaged in orthodontia, the reshaping of the oral structures, so the chiropody profession has been developing the science of orthodigita. It might be pointed out, however, that it is easier, relatively speaking, to control the position of fixed oral structures, consisting in the main of teeth, than it is to control and reshape movable functioning elements such as the phalanges and joints of the toes.

Essential to the management of orthodigital problems is, of course, a clear picture of the correctly aligned digital segments. These provide functioning units which help to stabilize the body balance in standing, make propulsive purchase in gait, raise the body in vertical action, respond to various resilient walking surfaces in degree of pressure, adjust to uneven surfaces as required to stabilize foot action, compensate for inadequacies of metatarsal structure, and control pivotal action in the direction of weight-force flow

The highly developed foot of the native of Melanesia, as described by James, has strong active toes which are straight, and each one is in the line of its metatarsal These toes form an additional basis of support for the anterior pillar and give the final push-off in walking, while their tendons, along with the small muscles of the foot, act as a bow string to prevent spreading of the arch when the

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toe. Innumerable references may be made to the native feet of many races, and it is generally agreed that the toes follow the line of the metatarsal bones and that a mild varus of the hallux is present in the unshod feet.

There are several factors that must be borne in mind when dealing with orthodigital problems. We must recognize the necessity of projecting the program of orthodigita for a specific case over a substantial rehabilitative period. Radiographs should be made when the case is begun and again at the end of a one-year period. This progress record may be supplemented by models and clinical photographs. Persistent rehabilitative work is the key to the success of Polokoff, who has devised an extensive series of orthodigital devices of felt which re-enlist the function of toe-controlling muscles and prop the toes into a functioning position.

In addition, it must be kept in mind that the patho-anatomy of the total foot cannot be ignored. An out-of-balance foot will surely affect the digital function. Levy's appliance to induce toe flexion while weight-bearing consists of a molded crest on a plantar appliance which has been a basic development that transposes the conventional shoe into more functional footgear. Developments of this type are of particular importance, since the majority of all toe distortions, aside from those resulting from congenital malformations of the toes, are caused by footgear, as a result of either poor fit or improper shape. The actual details of shoe construction contribute to toe malformation. It is an unfortunate fact that one pair of shoes can create a permanent disfigurement of a toe. The constant splinting of the toe in mal-alignment by a faulty shoe shape is just as persistent a device as an orthodigital device that might be used to straighten a toe.

A minority of toe deformities are caused by the following contributory factors: general foot collapse in which the foot elongates and the great toe is deflected, cavus foot types with contraction of the toes, arthritic deformities, and other congenital deformities and neuromuscular diseases

The lesions and other painful effects that result from orthodigital lesions consist of excrescences, bursitis, and neuritis. The inescapable reaction of epidermis to friction is the production of an excess of keratin that forms a painful excrescence The various orthodigital malformations provide the point of friction and the shoe is the counter-irritant. A detailed description of these lesions will be given from the radiographic visualizations

The major orthodigital lesions affect the hallux because of its imposing part in foot function They are hallux valgus, hallux varus, hallux flexus, and hallux limitus In addition there are lesser toe problems, consisting of overlapping and underlapping toes, hammer toes, and minimi digiti quinti varus. Sesamoid lesions are associated with hallucal problems

HALLUX VALGUS

One of the most common digital deformities of all people who wear shoes is valgus deformity of the first toe Without a doubt, every case is acquired, even though it has been recognized in children at an early age An obstetrician who was consulted claims that he has never observed hallux valgus deformity in several thousand births

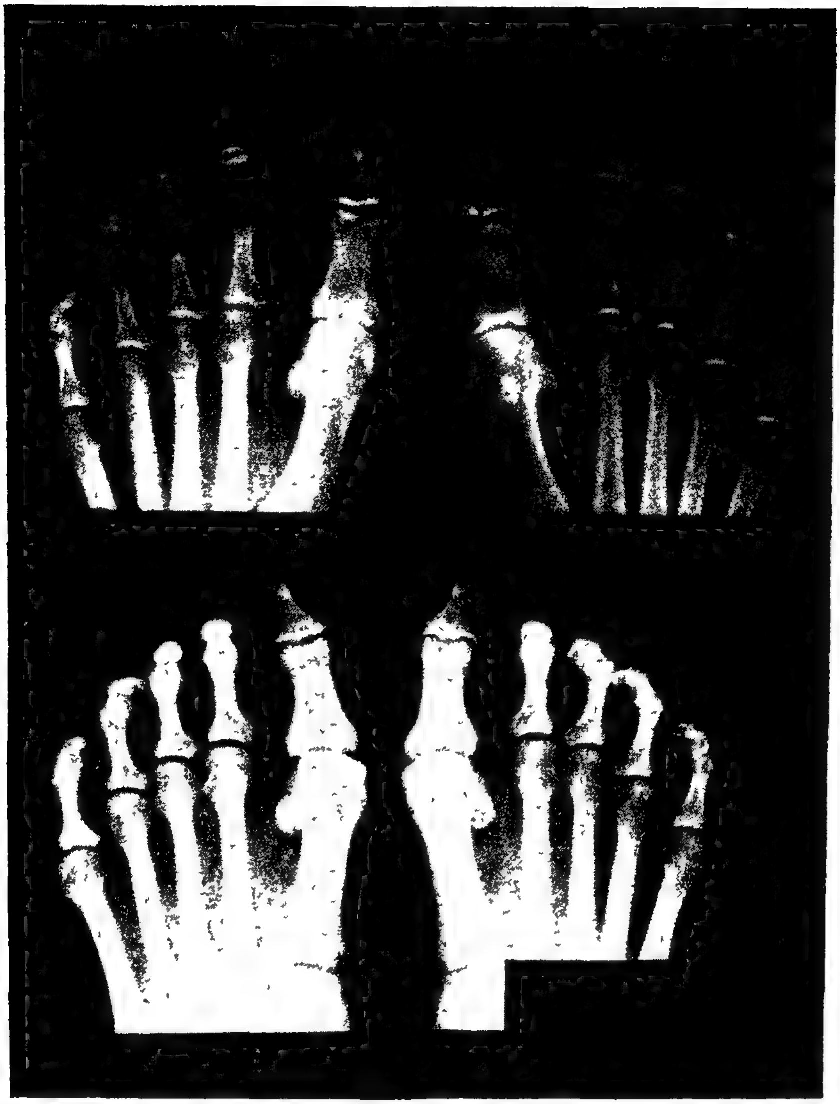

FIG 163 NATIVE FOOT—ASSAM, INDIA Top. relaxed attitude, toes posed in natural straight alignment with metatarsals Bottom. position used in hill climbing, toe flexion and slight hallux valgus

body weight is put on it. The first metatarsal and the great toe are adducted. This foot type is the epitome of normalcy, with the digital pattern unblemished. The first toe follows a normal adduction that is much the same as that found in the newborn. The lesser toes, although straight in alignment, are slightly flexed so that the pads at the ends of the toes assume a touching position.

The same foot type was described to the author by a native youth of Assam, India, who is presently enrolled in an American medical school. Although he characterized this foot type as typical of his race, he made this interesting distinction. The people of the plains country have flat toes, whereas his tribe, which lives in the hills and mountains, have curved toes from digging in while walking (Fig. 153) Hallux valgus deformity was unknown to him, since the hallux assumed a varus position and a thong was worn between the hallux and the second

the deformity in question may relate a poor economic situation in childhood which resulted in shoes being passed down from one child to another. In other instances the purchase of shoes without the child present for fitting supplies the background for the problem. The unreasonable attitude of preferring high-heeled pumps for duty wear, taken by many adult women, accounts for a big segment of the cases (Fig. 154).

Patho-anatomy There are several conditioning effects in the development of hallux valgus. The most important anatomical consideration should relate to the basic articulation of the cuneiform and the first metatarsal bone. The first metatarsal assumes a divergence of 6.2° in the average adult foot. The shape of the base of this bone provides the key to this position.

Under normal circumstances a line drawn through the long axis of the first metatarsal should be practically perpendicular with the articulation at the base of the first metatarsal bone Under this circumstance the first metatarsal would assume its normal position, provided that the medial cuneiform presents an articulation with the base of the first metatarsal, that is perpendicular with the long axis of the cuneiform.

When metatarsus primus varus exists, the base of the first metatarsal takes on an unusual shape in which there is excessive bone on the side adjacent to the base of the second metatarsal; as a consequence, the metatarsal bone assumes a position varus from a normally shaped cuneiform articulation. It has been our observation that pseudo-metatarsus primus varus may exist when the base of the metatarsal bone is normal but the shape of the medial cuneiform is elongated on the side adjacent to the second metatarsal, thereby creating an angulated articulation which bases the metatarsal bone in a varus position. A foot with these congenital, atavistic bone shapes is more predisposed to hallux valgus deformity than one that enjoys normal bone shape.

The varus position of the metatarsal bone in the unshod foot should merely indicate the divergence of the hallux Unfortunately, the shoe draws the hallux toward the midline of the foot in valgus position As a result, a vicious cycle of muscle imbalance occurs, and the organization of the joint is damaged. The flexor brevis hallucis and the adductor hallucis lose their effective pull upon the hallux to the extent that the adductor hallucis transversus and adductor hallucis obliquus draw the base of the proximal phalanx out of position. In addition, the peroneus longus, which is attached plantar-wise to the base of the first metatarsal overcomes its opponent, the tibialis anterior, so that the first metatarsal rotates on its long axis These two movements, of the proximal phalanx moving laterally and the first metatarsal rotating medially, allow the flexor hallucis longus to become displaced laterally and the distal phalanx rotates medially under the tension The sesamoid bones lose their articulated position under the condylar facets of the first metatarsal and become displaced laterally, and the middle sesamoid turns sidewise and lies in the interspace between the first and second metatarsal bones, while the external sesamoid bone assumes a role of increased weight distribution under the middle of the head of the metatarsal.

From our understanding of the divergence of the hallux in varus alignment at birth, and in the normal primitive, unshod foot, and other instances of native feet, we may safely assume that the hallux should be in a position of adduction The ray-like spreading of the metatarsal bones and their contiguous toes varies in individuals, thereby creating different amounts of adduction of the great toes. When the natural foot type is confined in socks and shoes, the toes are drawn toward the midline of the foot so that the hallux gradually assumes a valgus position The process may be very insidious, beginning when the infant foot is improperly covered by a short bootie or sock. The pointed shoe or short shoe of childhood does irreparable harm. Many an adult with

Figs. 154–161. Hallux Valgus Problems

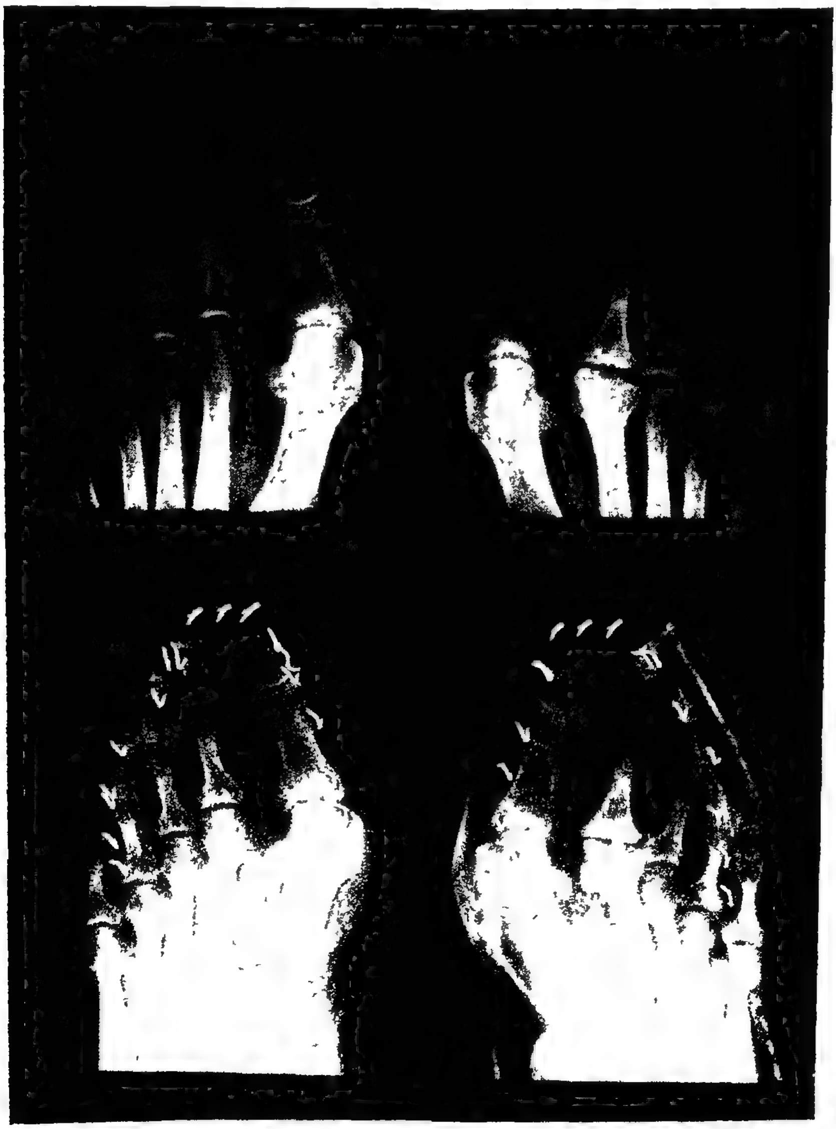

FIG. 154 INFLUENCE OF FAULTY SHOES Hallux valgus accentuated. Frieberg's infraction of second metatarsal head a coincidental exploratory finding

FIG 157 HALLUX VALGUS—SEVERE DEGREE Metatarsal varus; extreme hallux valgus; rotation of hallux, displacement of sesamoid bones into interspace, dislocation of both second and third toes by mal-directed hallux

Severe Hallux Valgus (Fig. 157)

(1) The hallux assumes an acute valgus position
(2) The hallux is rotated to a sidewise position.
(3) The hallux underlaps the second toe, creating a secondary displacement of the second toe and sometimes of the third toe.
(4) The proximal phalanx of the hallux is almost disarticulated from the metatarsal head
(5) The first metatarsal bone assumes an extreme varus condition.
(6) The first metatarsal is rotated and the head of the bone assumes large proportions, as a result of the radiographic position. Eburnation and defective molding exist.
(7) Both medial and lateral sesamoid bones lie in the interspace.

FIG 155 (Left) HALLUX VALGUS—MILD DEGREE Metatarsus primus varus, slight valgus of the hallux, eburnation on medial aspect of first metatarsal head

FIG 156 (Right) HALLUX VALGUS—MEDIUM DEGREE Metatarsal varus, hallux valgus, displacement of sesamoid bones, eburnation on medial aspect of first metatarsal head

Radiographic Impressions

Three stages of hallux valgus may be considered from a radiographic standpoint They are mild, moderate, and severe

Mild Hallux Valgus (Fig 155)

(1) Hallux is in a slightly valgus position in the unshod foot in a standing position
(2) The first metatarsal is divergent in the varus position.
(3) On the medial aspect of the first metatarsal head, eburnation exists

Medium Hallux Valgus (Fig 156).

(1) When the unshod foot is in a standing position, the hallux assumes a marked valgus position, crowding the second toe
(2) The first metatarsal is divergent in a definite varus position.
(3) There is increased eburnation on the medial aspect of the first metatarsal.
(4) The lateral sesamoid shifts toward the interspace and the medial sesamoid shifts to a position under the center of the first metatarsal head.

Metatarsus Primus Varus Predisposing to Hallux Valgus (Fig. 159).

(1) The base of the first metatarsal is elongated and enlarged on the side adjacent to the second metatarsal, thereby creating an oblique joint line as related to the long axis of the first metatarsal.
(2) A normally shaped medial cuneiform with its digital articulation perpendicular with the bone will direct the first metatarsal of atavistic shape into varus alignment.
(3) The hallux is forced into a valgus position from its position of imbalance, resulting from lateral pressure.

Secondary Subluxation of the Second Toe

(1) The distal phalanx of the hallux underlaps the second toe, forcing it into contraction and subluxation.

Clinical Considerations

(1) Bursitis and excrescence formation are the lesions that result from excessive friction and pressure upon the medial aspect of the metatarsal head. The excrescence may be reduced operatively. The bursitis may be relieved by negative galvanism, an astringent medicament, or ultrasonic radiation. Adequate protection and padding should be instituted immediately.
(2) *Mild* cases, in which there is a normal basal articulation of the first metatarsal, respond to traction, rotation exercise, strengthening of the abductor hallucis and flexor brevis digitorum, electrical muscle stimulation, and proper shoes.
(3) *Moderate* cases may be improved by the application of protective devices and by the same routine treatment given mild cases. In addition, day and night splints should be employed.
(4) *Severe* cases defy corrective measures and must be accommodated by a molded shoe or modified by surgical intervention.
(5) Choice of the surgical procedure to follow depends upon the anatomical situation. Atavistic bone shapes at the basal articulation should be dealt with by means of the Lapidus type of wedge resection and fusion at the base. Moderate cases respond to the Kellar procedure in which the base of the proximal phalanx is resected to straighten the toe (Fig 160). Mild cases in which there is an irritating factor of eburnation may be reduced by excision of the excess bone. Using these basic surgical procedures as a guide, the individual condition should be modified with as much tendon, capsular, and ligamentous repair as is deemed advisable Excision of the sesamoid bones is indicated when they are osteochondritic or a poor weight-bearing risk. Excision of the entire first metatarsal head should not be resorted to except in dire circumstances
(6) Amputation of the contracted second toe caused by an underlapping hallux valgus may be indicated if it is the chief offender.

FIG 160 HALLUX VALGUS—SURGICAL INTERVENTION Kellar procedure Excellent results. The second toe should have been repaired. A painful heloma durum on the dorsum of the interphalangeal joint required later surgery

FIG 161 HALLUX VALGUS—SURGICAL INTERVENTION. Hammer toe amputated No drifting of hallux valgus.

HALLUX VARUS

It is a sad sign of a modern civilization that would classify a varus position of the hallux as a deformity As has been previously emphasized, the normal foot should present a hallux in the varus position in support of a strong forefoot and toe design. Our consideration of hallux varus is mainly as a curiosity in finding an undistorted foot The author has seen one case, in which a flexible extreme inflare shoe had been worn by the individual for a lifetime, with a resulting hallux varus (Fig. 162).

Surgery directed at improvement of hallux valgus has on occasion gone astray so that the hallux has been diverted into a varus position (Fig 163). This is a very sad post-operative situation Poor reconstructive judgment is responsible for such a disaster. This deformity may be created by excision of too much of the metatarsal head which reduces the articulating area to too small a margin, by too much reefing of the capsule, or by uncompensated muscle imbalance It should serve as a warning that all but the well-trained should be wary of hallux valgus surgery

FIG 162 HALLUX VARUS Normal bone shapes enter metatarso-cuneiform articulation This foot has been shod in a flexible, inflare last for a lifetime Note unusual bone condensation of second and third metatarsal shafts resulting from stress pattern Third, fourth, and fifth toes distorted in coping with gait Mid-tarsal fault persists

FIG 163 HALLUX VARUS. Postoperative disaster Result of poor judgment in hallux valgus surgery

Radiographic Features

The hallux assumes a varus or straight alignment with the first metatarsal shaft.

HALLUX FLEXUS

Flexion of the inter-phalangeal articulation of the great toe creates a deformity that may be extremely annoying. Adventitious bursa and, eventually, excrescences may be formed on the dorsum of the toe. The malposition is secondary to muscle imbalance, in which the flexor hallucis longus is over-active. This may be the result of the inadequate structural stability of the medial arch segment, in which foot elongation has taken place because of mid-tarsal fault, thereby creating excessive tension on the long flexor (Fig. 164). Instances of excessive action of the flexor hallucis longus to compensate for lack of flexion of the adjacent second toe have been observed.

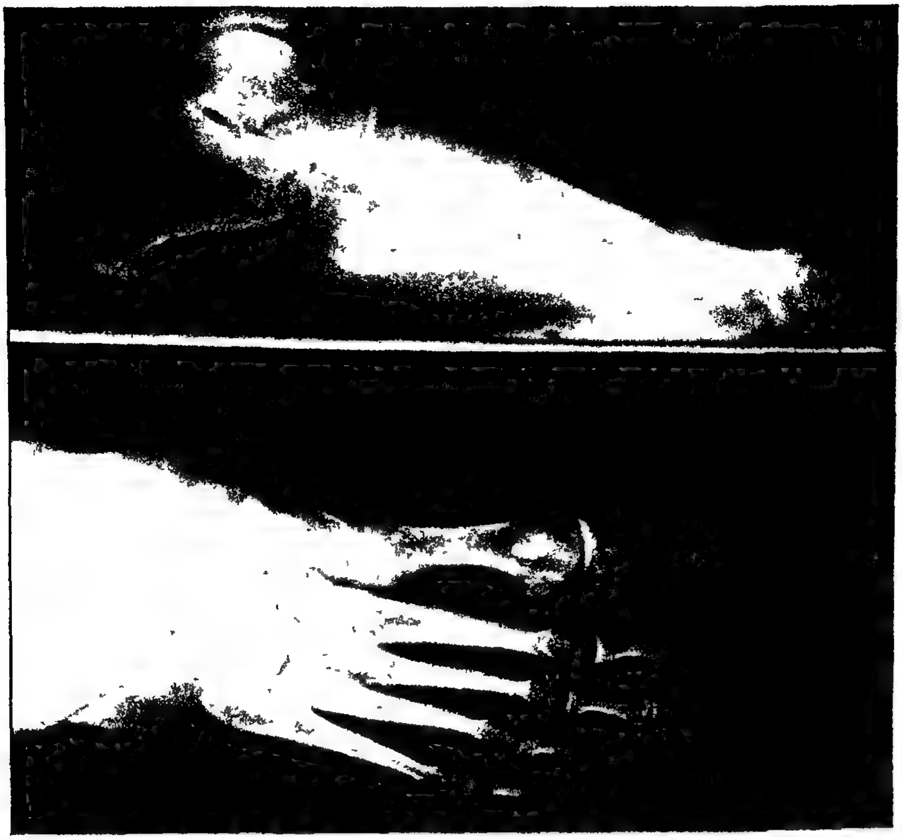

FIG. 164 HALLUX FLEXUS Inter-phalangeal involvement due to excessive tension of flexor hallucis longus in compensating for mid-tarsal weakness

Lapidus describes a flexion deformity of the first metatarso-phalangeal joint which he terms "dorsal bunion" in order to convey the clinical picture of the problem The metatarsal head is raised above the level of the adjacent joints and the medial cuneiform is also thrust upward. Excessive weight is borne by the inter-phalangeal joint of the first toe

Radiographic Features

(1) The joint space at the inter-phalangeal articulation of the great toe is closed

(2) Lateral deviation of the distal phalanx is observed.

Clinical Considerations

(1) Hallux flexus requires surgical repair.

(2) A dorsal bunion may be reduced by means of the procedure devised by Lapidus, which consists of wedge resections at the metatarso-cuneiform and cuneo-navicular joints. Also, considerable tendon transplants are made to reorganize the foot and toe positions The tibialis anterior is transplanted to the tibialis posterior tendon The flexor hallucis longus runs obliquely in a channel through the first metatarsal into the dorsal capsule of the first metatarso-phalangeal joint

(3) Some degree of palliative relief may be obtained by means of a metal foot appliance.

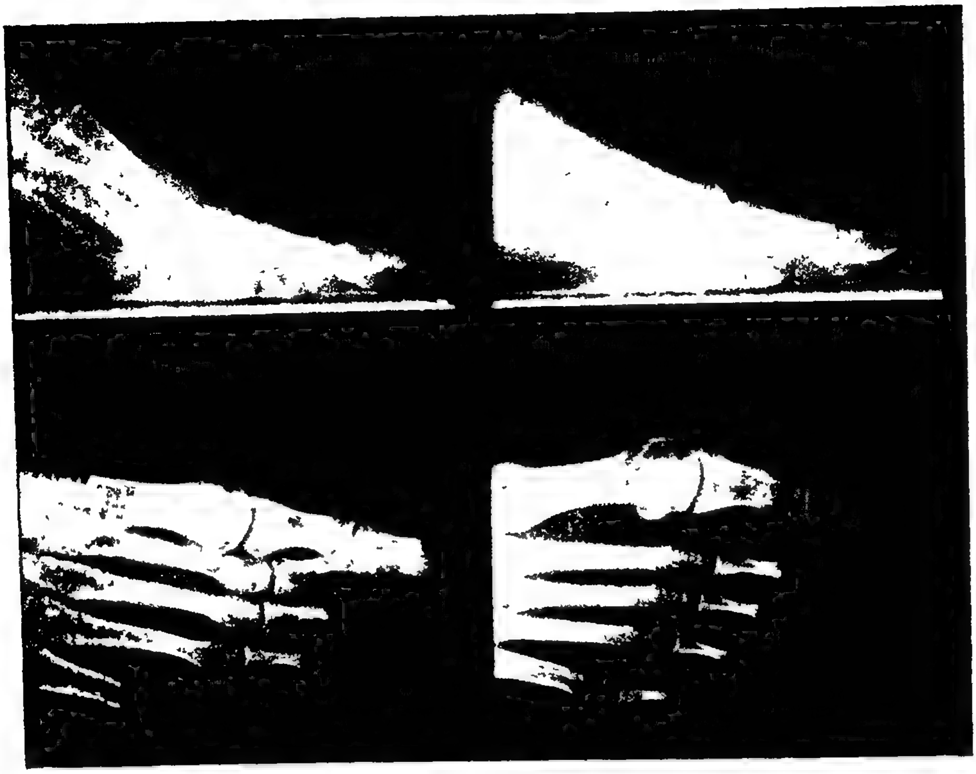

FIG. 165. HALLUX LIMITUS—MILD DEGREE. Limitation of extension shown by comparison of functional and standard lateral view. Loss of joint space in dorso-plantar view. Modeling of metatarsal head shown in dorso-medial view.

HALLUX LIMITUS

Many clinicians have reported a pathological condition of the first metatarso-phalangeal joint in which motion in the joint is restricted. They have designated this condition as hallux rigidus. According to our experience, this term is a misnomer, since some degree of motion is present. However, it is limited and so we prefer to refer to the problem as hallux limitus.

Hallux limitus may be restricted to one foot, which emphasizes the local character of the pathologic process. It is our contention that minimal traumata is the basis for the degenerative changes that take place in the articulation. This may result from the wearing of short or tight shoes which exert pressure on the joint. An extremely flaccid foot type that elongates the great toe against the restriction of the shoe may also be a cause. Still another possible factor is elongation of the foot with subsequent pressure on the great toe, such as occurs in mid-tarsal fault.

The sequence of pathology may be traced from radiographs of mild, moderate, and severe cases The first reaction is peri-arthritis. Little radiographic evidence of this will be found, other than the restriction of motion demonstrated by the range of metatarso-phalangeal extension visualized in a functional view of the foot in which it has been carried to the point of pain. In the next stage, ravages of cartilage degeneration are demonstrated such as flattening and molding of the metatarsal head and eburnation and calcification with osteophytic ridges traversing the head of the bone and extending dorsally. The severe stage

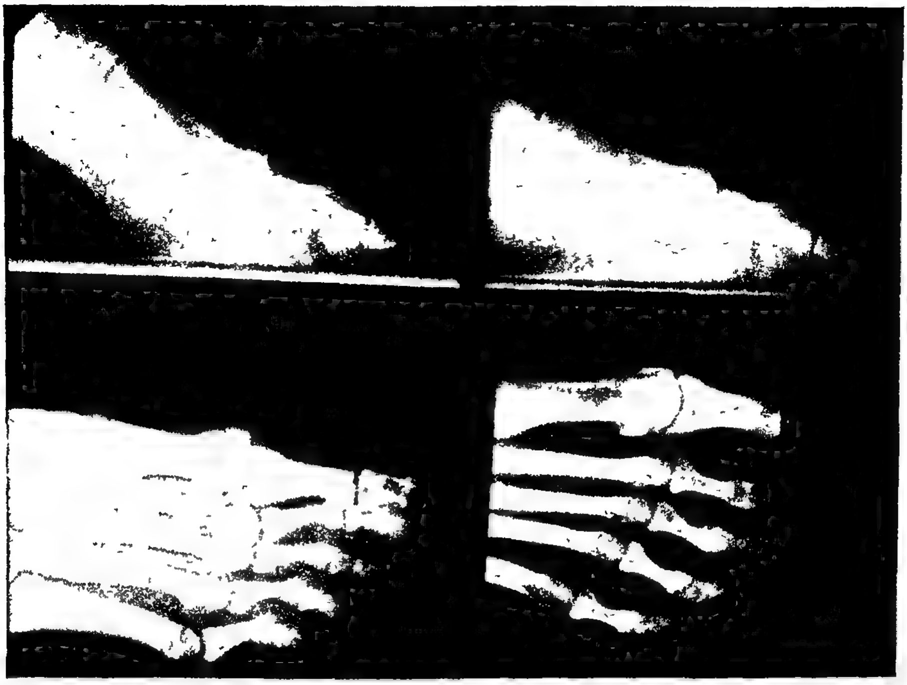

FIG 166 HALLUX LIMITUS—MEDIUM DEGREE. Limitation of extension; degenerative change in shape of metatarsal head; exostotic formation shown in functional and standard lateral views Loss of joint space and modeling of metatarsal head shown in other views

presents a paradox, in that the lateral view of the metatarso-phalangeal joint seems to show increased joint width at the superior margin This might seem to imply that free joint motion is present; on the contrary, as soon as the toe moves into extension the space is immediately closed by a jamming of the base of the phalanx against the degenerated metatarsal head because the normal cartilage elements of the joint have long since disappeared

A frequent complication of hallux limitus consists of referred pain as a result of impingement of nerve branches by the exostotic formations that extend toward the second metatarsal head. The dorso-plantar view is likely to be misleading concerning the extent of the exostosis formation. The only evidence of the ridge-like eburnation may be a line of increased density Lateral views are imperative to identify the true outline of the new bone formation

Radiographic Impressions

Depend on a series of views comparing the lateral view of the metatarso-phalangeal joint with the lateral view of the joint extended to the point of limitation and pain The dorso-plantar view and the dorso-medial view demonstrate the extent of the involvement.

Mild Hallux Limitus (Fig 165).

(1) Loss of joint space may be visualized in the dorso-plantar view
(2) Limitation of joint extension may be visualized from a comparison of lateral and functional views

Moderate Hallux Limitus (Fig. 166).

(1) Flattening of the metatarsal head and loss of joint space may be visualized in the dorso-plantar view.
(2) An area of increased density traversing the base of the proximal phalanx and indicating bone eburnation may be seen in the dorso-plantar view.
(3) Comparison of the lateral and functional views demonstrates limited joint extension.
(4) The lateral view shows increased joint width at the superior margin of the joint as the result of degeneration of the joint constituents.
(5) The exostotic formation and modeled metatarsal head are visualized in the lateral view.

Severe Hallux Limitus (Fig. 167).

(1) When visualized radiographically in the dorso-plantar view the joint space is practically obliterated
(2) Exostotic formation and areas of increased density traverse the metatarsal head and proximal phalanx as visualized in the dorso-plantar view.

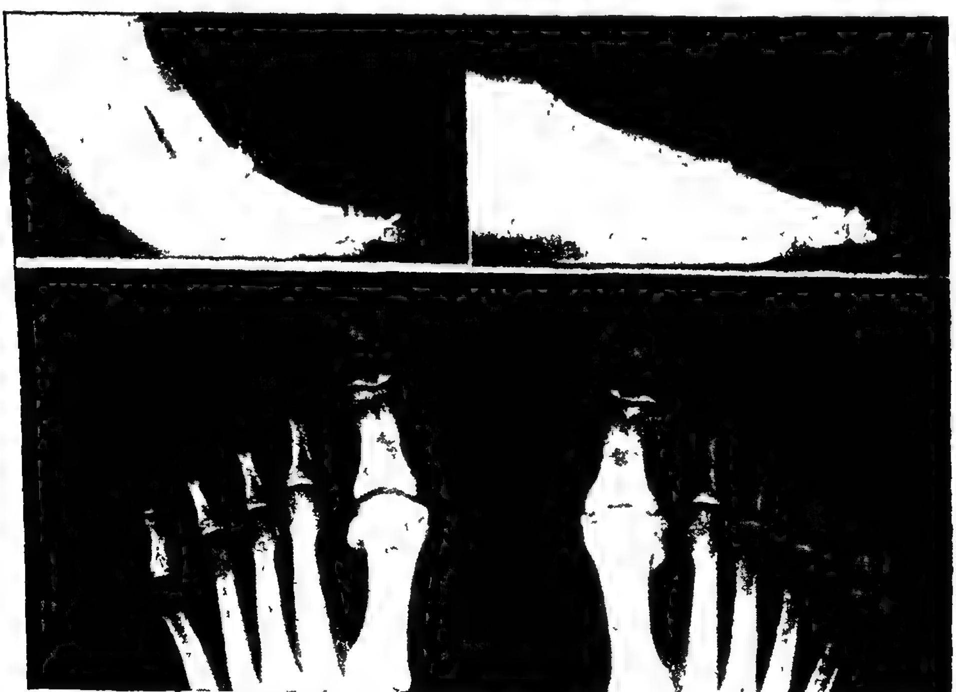

FIG 167 HALLUX LIMITUS—SEVERE DEGREE The unilateral predominance in this case is noted in the comparative dorso-plantar view Also note the loss of joint space and hyperostotic formations In the lateral view, note especially the apparent increase of joint space in the standard lateral view resulting from loss of joint constituents. The functional view shows that the joint "jams" instead of allowing a normal range of motion around the perimeter

FIG. 168 OVERLAPPING AND UNDERLAPPING TOES. Radiographic evidence of all factors contributing to the problem, hallux valgus, subluxed third toe, lateral luxation of fourth toe which is underlapping.

(3) In some cases the lateral view demonstrates free calcified bodies in the joint space. In dorsal projection, the extent of calcification is also seen.

(4) Comparison of the lateral and functional views demonstrates the very limited range of motion with jamming of the joint constituents

Clinical Considerations

(1) Cognizance must be taken of the peri-arthritis in every case of hallux limitus. Treatment directed at a reduction of the symptoms of this syndrome should be instituted Hydrocortisone acetate and other steroid paracenteses have proved effective in many cases In addition, there are the usual applications of negative galvanism, heat applications, histamine preparations for vasodilation, paraffin therapy, ultrasonic therapy, and traction for the relief of pain.

FIG 169 HAMMER TOE—TYPE 1 Base of proximal phalanx closes joint space Proximal interphalangeal joint closed. Distal interphalangeal joint closed Medullary cortex of distal phalanx emphasized

FIG 170 HAMMER TOE—TYPE 3 Metatarsophalangeal joint space open Inter-phalangeal joint space closed. Distinctive "shining diamond" appearance of medullary cortex of distal phalanx due to plantar flexed position

(2) Also of value is mechano-therapy, consisting of a soft leather shoe, to relieve dorsal pressure on the enlarged joint, with a stiff sole made by the addition of an extra sole This shoe restricts joint motion and relieves aggravation of the condition.

(3) In severe cases surgical intervention may be resorted to in order to create a pseudo-joint in which the offending elements have been removed.

OVERLAPPING AND UNDERLAPPING TOES

Probably the most common instance of overlapping and underlapping toes is exemplified by the situation that develops in hallux valgus, where the second toe is displaced above the hallux (Fig 168). This problem has been discussed in detail under "hallux valgus," near the beginning of this chapter.

Occasionally, underlapping toes are present at birth In these instances they are the result of soft-tissue anomalies. Fibrous restricting bands of ligament tissue are the usual offenders. Judicious splinting of the infant's toes with adhesive tape usually suffices to straighten the member.

Distortion of the toes by pointed shoes may create this problem in the adult and correction will require orthodigital devices.

Radiographic Features

The dorso-plantar view demonstrates the toes involved as super imposed. From this single view it is impossible to determine which toe overlaps and which underlaps. Clinical findings are sufficient.

HAMMER TOES

When a toe is distorted in a flexed position it is commonly called a hammer toe because of the similarity to the position of a hammer head on a handle. Either the single or the bilateral hammer-toe problem is frequently a congenital anomaly resulting from a short tendon slip to the distal phalanx and from other soft-tissue restrictions which hold the toe in flexion. This condition is the true deformity. Other instances of a toe being held in flexion include contractions incident to patho-mechanical mal-functioning of the foot, and toe deformity precipitated by hallux valgus on its adjacent members. Rheumatoid arthritis creates hammer toes by loss of power of the short flexors, lumbricales, and interossei muscles.

Budin classifies all flexion deformities, whether congenitally fixed or acquired contractions, within four distinct types of hammer toes.

(1) The metatarso-phalangeal joint is hyperextended and the proximal inter-phalangeal joint flexed The distal inter-phalangeal joint may or may not be flexed.

(2) The metatarso-phalangeal joint is hyperextended and the proximal inter-phalangeal is flexed. The distal inter-phalangeal may be hyperextended, and sometimes it stimulates a flail joint.

(3) The metatarso-phalangeal and proximal inter-phalangeal joints are practically in a normal position, but the distal inter-phalangeal joint is flexed. (This is usually congenital.)

(4) This is a variation of type one, but the proximal phalanx is dislocated upward and backward on the head of the metatarsal bone Such dislocation at the metatarso-phalangeal joint is usually complete.

Radiographic Features

Type (1). The base of the proximal phalanx is superimposed over the head of the metatarsal. The proximal inter-phalangeal joint space is obliterated, as is the distal inter-phalangeal joint space (Fig. 169).

Type (2). This is the same as type one, except that the distal inter-phalangeal joint may be visualized if the toe is flail.

Type (3). The base of the proximal phalanx may or may not be superimposed over the head of the metatarsal. The proximal inter-metatarsal joint may be visualized The central ray passing directly through the cylindrical medullary portion of the distal phalanx creates a very distinctive radiographic appearance in the form of a circle of increased density (Fig 170).

Type (4). The base of the proximal phalanx is superimposed over the head of the metatarsal to a considerable degree The proximal inter-phalangeal joint may be open but the distal one is obliterated

Clinical Considerations

The following have been found of use:

(1) Orthodigital devices, traction, and exercise are employed in straightening hammer toes In cases that are irretrievable by these methods, surgery may be resorted to.
(2) Budin uses a system of specific splints under the toe with latex bands designed to exert influence over the desired areas.
(3) Polokoff places felt build-ups under the toes to exert a straightening effect.
(4) Flexible plastic crests have been devised by Kemp.
(5) The Levy mold is effective.

MINIMI DIGITI QUINTI VARUS (Fig. 171)

Displacement of the fifth toe into a varus position is a relatively common problem. It is popularly called "Tailor's Bunion" and derives from the story that an old-time tailor developed the condition from always sitting cross-legged and, consequently, with the weight on the head of the fifth metatarsal. Today pointed footwear is the most common cause. Locke draws attention to a syndrome which he claims involves a transfer of weight from a painful hallux rigidus to the lateral border of the foot, thus causing "Tailor's Bunion," with neurovascular heloma, callus (under the fifth metatarsal head), adventitious bursa, and exostoses.

Radiographic Features

(1) The proximal phalanx of the fifth toe deviates into a varus position with the shaft of the fifth metatarsal.
(2) From the dorso-plantar view, it can be seen that the middle and distal phalanges also assume a varus position.
(3) The fifth metatarsal segment may exhibit laxity as a result of the spreading of its basal articulation with the fourth metatarsal.
(4) The fifth metatarsal may rotate medially on its long axis

Clinical Considerations

(1) Budin recommends traction splints and a rubber band sling to draw the toe into correct alignment Additionally, he suggests taping the fifth metatarsal into proper position if it has become rotated.
(2) Properly shaped footwear is imperative
(3) Lantzounis describes a periosteo-capsuloplasty for correction of congenital subluxation of the fifth toe He claims that the pathogenesis is prolonged malposition of the fifth toe during intra-uterine life rather than failure of proper development. The patho-anatomy consists of a short extensor digitorum longus tendon to the fifth toe. Skin, fascia, and capsule at the medio-dorsal surface are contracted His operative procedure consists of the following: The extensor digitorum longus tendon to the fifth toe is divided. He makes a longitudinal incision of the

FIG 171 MINIMI DIGITI QUINTI VARUS WITH SUBLUXATION VARUS OF FIFTH TOE Subluxation of fifth metatarso-phalangeal articulation This neutralizes to some extent the prominent metatarsal head with hyperostotic formation on the lateral border which is a typical finding

periosteum from the distal end of the fifth metatarsal, to the capsule, and the periosteum of the proximal phalanx and then elevates the dorsal, lateral, and medial surfaces, leaving the plantar attachments undisturbed He then drills a tunnel in the distal end of the fifth metatarsal, threads the extensor digitorum longus tendon through it, and sutures it back on itself A mattress suture is made in the periosteocapsular flap under the fifth metatarsal under the phalangeal neck. This flexes the toe The tension stabilizes it in a normal position

(4) A distinction between the simple type of problem and the congenital one must be made.

FIG. 172 SESAMOID LESION Osteochondrosis medial sesamoid—secondary to mal-position in hallux valgus

(5) In many cases amputation of the fifth toe has been performed, but it is ill-advised in most instances due to the frequent development of post-operative problems at the head of the fifth metatarsal.

SESAMOID LESIONS

The sesamoid bones associated with the flexor hallucis longus tendon are subject to a variety of problems. The mobility of these bones is enhanced by their location in the tendon that attaches to the proximal phalanx of the hallux. Provisory articulating surfaces are made on the head of the metatarsal which, under normal circumstances, establishes their rightful position, one on either side of the bone According to Morton these bones assume two units of body-weight distribution

FIG 173 SESAMOID LESION Absence of medial sesamoid Note hypertrophy of second metatarsal shaft

In hallux valgus deformity, the sesamoid bones shift toward the midline of the foot, with the result that the medial sesamoid takes a central position under the head of the metatarsal and the lateral sesamoid bone moves to the interspace between the first and second metatarsal bones In this circumstance the medial sesamoid bone receives a disproportionate amount of weight force, and in time the fibrocartilage undergoes mineralization, which results in a bizarrely shaped sesamoid bone Often the osteochondritis condition causes frictional problems with the metatarsal head, and the normal movement of these bones is impeded, with resultant sesamoiditis (Fig 172) In other instances, the sesamoid bone becomes fragmented, due to the fragility of the osseum and the newly imposed burden. Secondary lesions on the skin surface consist of neurovascular tyloma as a result of the irregular counter-pressure.

Bipartite sesamoid bones may be a congenital anomaly of no consequence; on the other hand, symptoms are likely to occur if excessive weight is thrust upon it

FIG 174 SESAMOID LESION. Osteochondrosis medial sesamoid and external sesamoid—secondary to high arch foot-type

Multiple division of a sesamoid bone is often encountered and may be the result of microtraumata or, in the opinion of the author, of gouty disintegration of the sesamoid

Absence of the sesamoid bones has been noted in several cases and apparently is a congenital anomaly The resultant disturbance in weight distribution is obvious (Fig. 173).

Radiographic Features

(1) In osteochondritis the dorso-plantar view shows enlargement of the sesamoid.
(2) Diminution of the joint space between the sesamoid and the head of the metatarsal can be visualized in an axial view of the sesamoid.
(3) The sesamoid bone is divided.

Clinical Considerations

(1) The difference between a fractured sesamoid bone and a bipartite one may be distinguished by the following means· in the fractured bone there is an irregular, serrated line of cleavage with sides that match and a lack of cortical density along the fracture line, while the bi-

partite bone demonstrates smooth contours of the division and cortical density throughout.

(2) Appliances should be designed with support along the shaft of the first metatarsal and deep cupping for the sesamoid area, plus a metatarsal platform under the lateral metatarsals to transfer the weight load away from the traumatized sesamoid area.

(3) Metatarsal shoe bars are effective in relieving sesamoid lesions

(4) Sesamoid lesions sometimes develop in highly arched feet because the sesamoid bones move to a position almost at the metatarso-phalangeal joint junction (Fig. 174). Pes cavus management is indicated

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Chapter IX

Excrescence Factors

The most common exciting cause of excrescence formation is microtraumata, as invoked by intrinsic pressure from an exostosis, and irregularly shaped toe bone, or a malposed phalanx. It is obvious that x-ray examination is most useful in evaluating these factors. The extrinsic pressure of footgear is an undeniable part of the twin team of pressure and counter-pressure that contributes to the production of the excrescence (Fig. 175).

It is well to consider other factors contributing to excrescence formation in order to make the scientific approach to the problem more complete. According to Sharpe, the skin of the individual is influenced by physiological factors. Systemic factors such as hyperthyroidism and other endocrine disturbances, faulty metabolism, anemia, inflammation, hemorrhage, hypertrophy, atrophy, anomalies of secreting glands, and neoplasms may also contribute. The basic condition of the skin provides the background for the production of excrescence, and the normal physiology of the skin sets up an exfoliative process that favors its development. Secondary pathology such as ulcerations due to peripheral vascular episodes may complicate the process Sometimes factors such as perforating ulcers due to the total effect of trauma, periphero-vascular embarrassment, and general senile changes of the skin complicate a common excrescence. Austin has investigated the idiopathic excrescence and has concluded that adhesion between the plantar fascia and the skin is responsible for triggering the production of the keratotic plug-like formations. According to Austin, "Recurrent excrescences on relatively straight digits result from stress over the expansions of the tendon sheaths over the joint capsule with resulting adhesion between these structures and the skin"

A study of the pressure and counter-pressure factors in the etiology of common excrescences brings to light some very interesting features.

Pressure is an extrinsic factor caused by foot covering, mainly shoes, although stockings also play a part The pressure upon the foot and toes caused by shoes is accounted for by incompatible shoe shapes, misfitting shoes, irregularities in shoe construction, use of faulty material in shoes, and improper types of shoes. Unfortunately, radiography is unable to be of much aid in the appraisal of these factors. Any properly trained person can better judge the merits of a shoe and its fitting qualities with the naked eye and digital inspection than he can with fluoroscopy or radiography Nevertheless, radiography lends itself to one

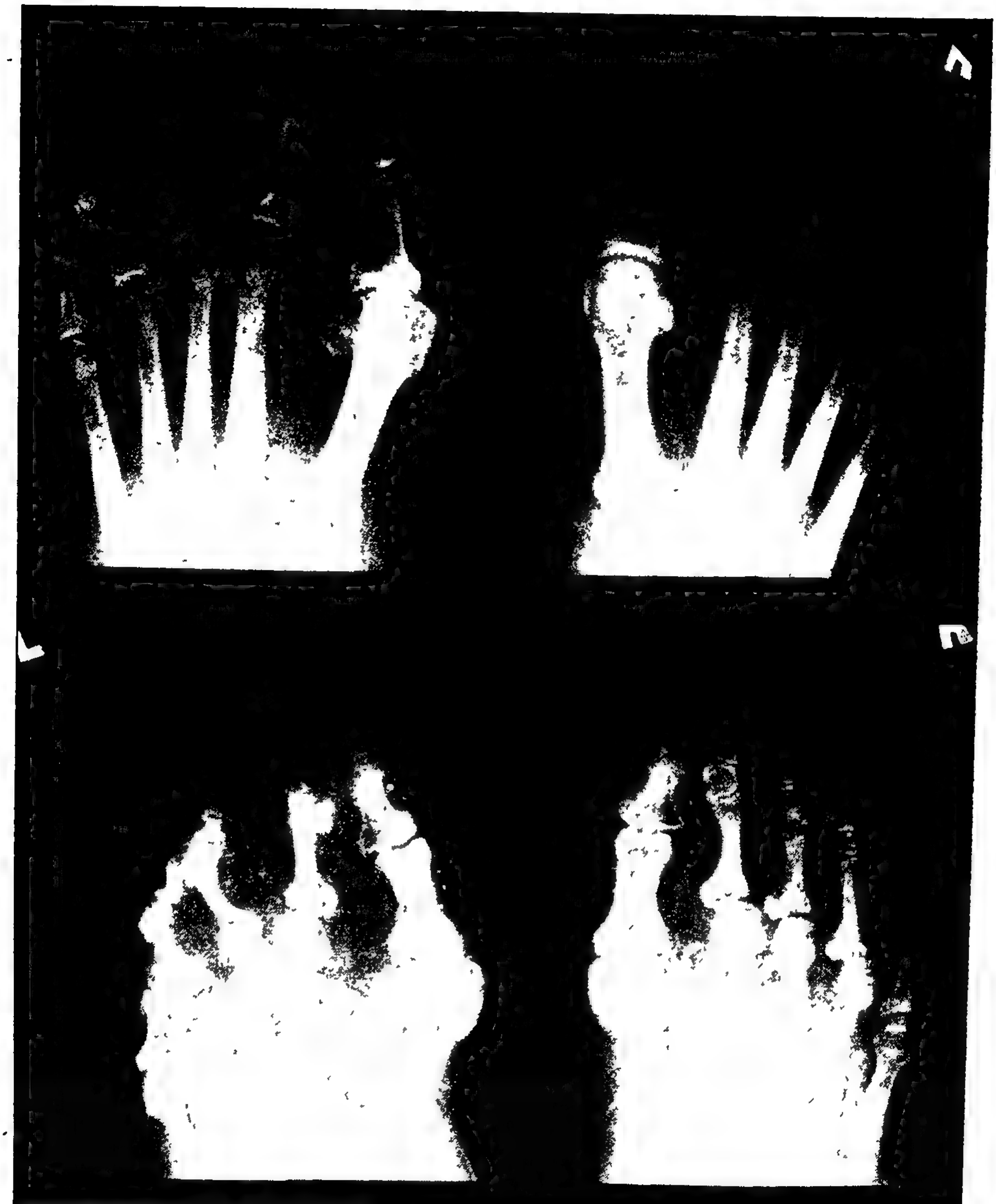

FIG 175 TWIN TEAM EXCRESCENCE ETIOLOGY Pressure—incompatible shoe Counter-pressure—mal-posed toes

phase of the appraisal. consideration of whether or not the shoe shape and the foot are compatible A radiograph of the shod foot definitely shows whether or not the toes lie in their normal relationships, provided that a radiograph of the unshod foot is available for comparison. To a lesser degree the fitting of the foot into the shoe may be estimated. When checking the length, one must bear in mind at all times that the fleshy parts of the toes account for at least a quarter of an inch additional length beyond the distal phalanx of the great toe. The width may be judged on the basis of crowding of the metatarsal heads, mal-alignment of the toes, and over-riding of the bones over the outline representing the sole of the shoe.

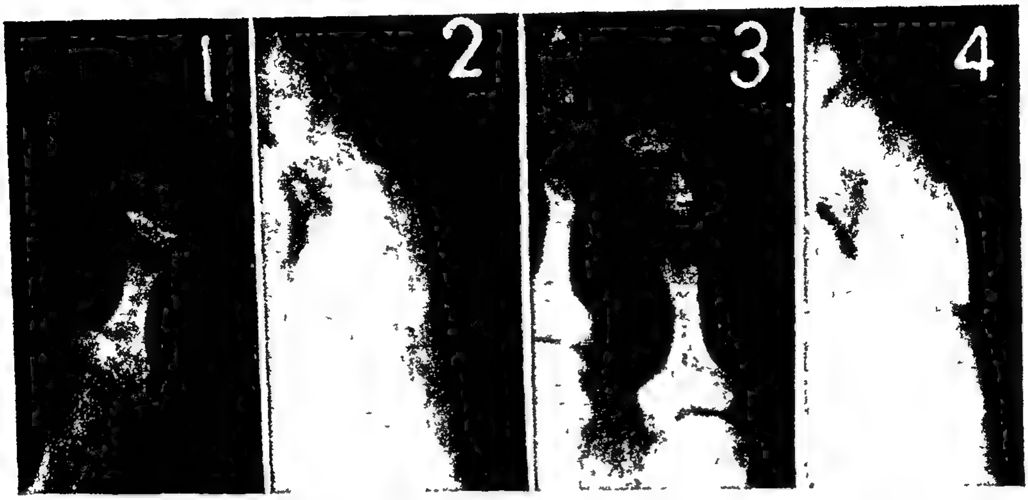

FIG 176 BASIC INTRINSIC EXCRESCENCE ETIOLOGY. (1) Mal-alignment, (2) exostoses, (3) roughened bone margins, (4) irregularly shaped toe bones; fusion middle and distal phalanges

Counter-pressure implies an intrinsic quality of the foot or toes that reacts with the direct pressure of the shoe, impinging on the skin and causing pathological excrescences. Radiography offers an unexcelled means for studying the varied intrinsic features that provide counter-pressure The basic intrinsic features include irregularly shaped toe bones, roughened bone margins, exostoses, and mal-alignments (Fig. 176).

Irregularly Shaped Toe Bones. These are inherent at birth and are probably due to evolutionary adaptation throughout the ages. Certain races have characteristic bone shapes, a fact which applies particularly to metatarsal bones and phalanges. All defects in development and growth of the metatarsal bones and phalanges create irregularities that may eventually lead to excrescences.

Roughened Bone Margins. These represent pathological changes that have taken place in the cortical margins of the involved bones and are frequently the result of chronic periostitis with the subsequent subperiosteal ossification. Microtraumatisms incident to shoe pressure, the ravages of arthritis, trophic conditions, osteomyelitis, and other bone pathologies account for a certain number of roughened bone margins.

Exostoses. These frequently result from continuous irritation of the periosteum by direct shoe pressure; in other cases they are caused by unequal or excessive strain at the attachment of the tendons. Still another group of exostoses are developed on the margins of the joints due to minimal traumatic arthritis and degenerative arthritis

Mal-alignments. Mal-alignments may be characteristic of the foot pattern at birth or may be acquired through foot and toe abuse Although faulty shoes are the most common cause, the patho-mechanical status of the foot must be given careful appraisal. If the foot becomes adducted through longitudinal arch depression, mal-alignment of the toes almost invariably follows.

The common skin excrescences consist of heloma durum, heloma molle, heloma vasculare, and tyloma These conditions vary in size, shape, and location in accordance with the intrinsic factors involved. A heloma durum may be round

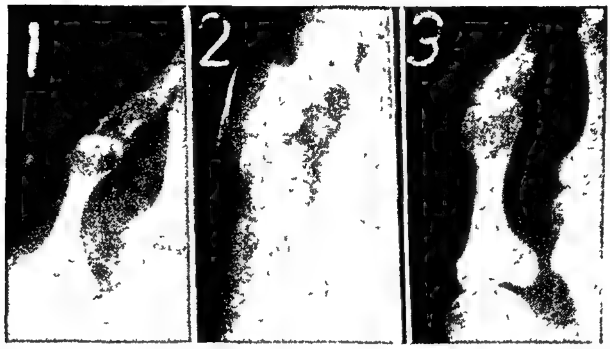

FIG 177 HELOMA DURUM FIFTH TOE—VARUS MAL-ALIGNMENTS (1) Varus of entire toe, (2) varus of middle and distal phalanges, (3) varus of distal phalanx

with a conical apex, oblong with a crescent-ridge apex, or irregular in shape and flat without an apex. The heloma durum may be located on the distal end of the toe, distally on the dorsum near the toe nail, over the medio-distal phalangeal articulation, over the medio-proximal phalangeal articulation, or in any combination of these positions

In the section that follows, size, shape, and location will be related to the intrinsic factors Each of the predominant conditions will be discussed separately, and the roentgenographic characterization of the intrinsic factors will be described.

HELOMA DURUM

Fifth Toe. Exostoses or roughened bones are present. These factors usually occur on the latero-distal portion of the proximal phalanx and are the result of periosteal irritation The cortical margins show the irregular outline of the roughened bone or the sharply spiculated outline of the true exostosis Invariably, the exostosis factor produces the deep-apex type of heloma, whereas the roughened bone produces the crescent-ridge type of exostosis.

At Temple University School of Chiropody a research project under the sponsorship of Dr Frank J Carleton was carried out by the author to determine the frequency of exostosis in the presence of heloma durum of the fifth toe, with the following interesting results:

Cases examined	501
True projecting exostosis	91
Roughened bone margins and/or irregular bone shapes	248
No exostosis, roughened bone margin, or irregular bone shape	162

Fusion of the middle and distal phalanges is a structural anomaly that is common. It accounts for many large heloma at the proximal inter-phalangeal joint because the shoe shape has a tendency to cause an acute bending of the toe toward a varus position, with subsequent friction because of the unyielding fusion.

Varus mal-alignments account for a variety of heloma, in accordance with the joints involved and the subsequent shoe pressure Definite heloma lesions

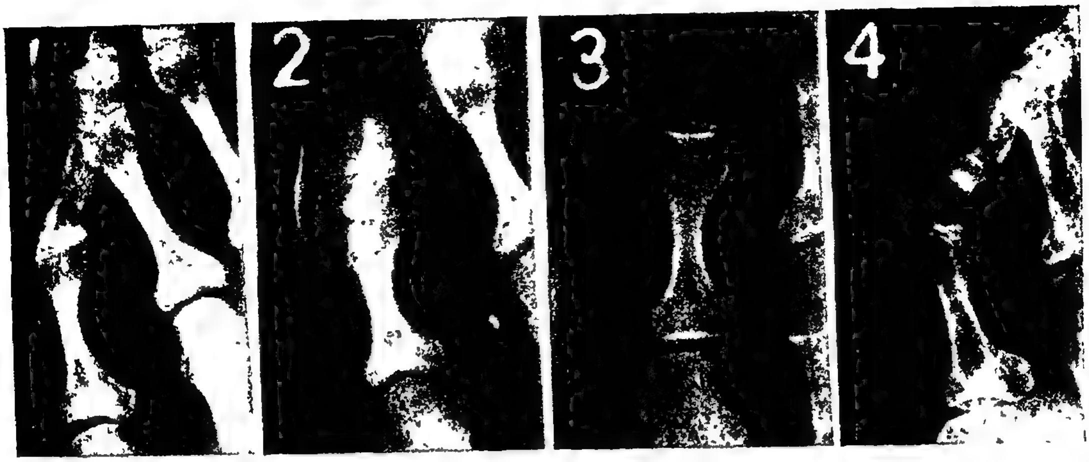

Fig. 178. Heloma Durum Fifth Toe—Rotation Mal-alignments (1) Rotation of entire toe, (2) rotation of middle and distal phalanges, (3) rotation of distal phalanx, (4) combination rotation and varus mal-alignment

have been demonstrated in the following combinations: varus of the entire toe, varus of the middle and distal phalanges, and varus of the distal phalanx (Fig. 177).

The intrinsic features of another series of heloma are represented by rotation of a toe or of the phalanges. The rotation is on the long axis of the toe, and the dorsum usually rotates laterally Roentgenographically, instead of the phalanx presenting the usual appearance seen in the dorso-plantar view, a lateral view of the involved bones is visualized. Heloma occur in the posterior nail groove and under the distal ends of the toes in these cases, as well as on the lateral aspect of the toes. The rotations may involve the entire toe, the middle and distal phalanges, or the distal phalanx only (Fig. 178).

Combinations of several of these factors are possible For instance, an exostosis of the head of the proximal phalanx may be present, along with a rotation of the entire toe in which the middle and distal phalanges have assumed a varus position.

Dorsum of the Intermediate Toes and the Distal Ends of the Toes. Contractions of the entire toe, of the middle and distal phalangeal joints, or of the distal phalangeal joint account for the heloma on the dorsum of the toes. These contractions force a bony prominence to react with shoe pressure to cause the heloma (Fig 179).

It is an interesting correlation that the toes are contracted in an effort to maintain body balance by the infirm or aged and that they are also contracted in an effort to relieve strain in cases of arch depression and to avoid pain in cases of plantar heloma.

The size, shape, and location of the heloma are directly related to the nature of the contraction. In acute contractions of the distal phalangeal joint, pressure is concentrated on the distal end of the toe and heloma of the deep apex type usually occur (Fig. 180). In this type of contraction, heloma will frequently be situated over the medio-distal joint.

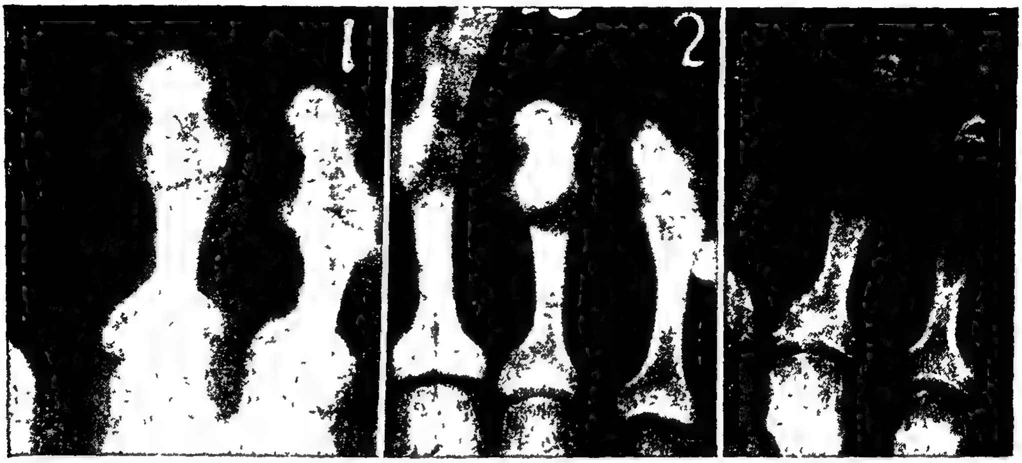

FIG. 179 HELOMA DURUM ON DORSUM OF TOES—CONTRACTION MAL-ALIGNMENTS (1) Contraction of entire toe—second and third (2) Contraction of middle and distal phalanges—third and fourth (3) Contraction of distal phalanx—third and fourth

The roentgen interpretation of toe contraction, when appraised in the dorsoplantar view, is based on loss of joint space and superimposition of the phalanges at the joint region. Contraction of the distal phalangeal joint places the distal phalanx in a position so that the central ray traverses the long axis of the bone, creating a circular ring of increased density on the radiograph

Clinical Considerations

(1) Conventional conservative procedures are well known

(2) Austin has made a most extensive survey of various techniques for permanent correction of the helomata by performing the surgical procedures on the cases and following the progress for two years. The results of his findings, along with some of those of Fowler can be seen in Table 2.

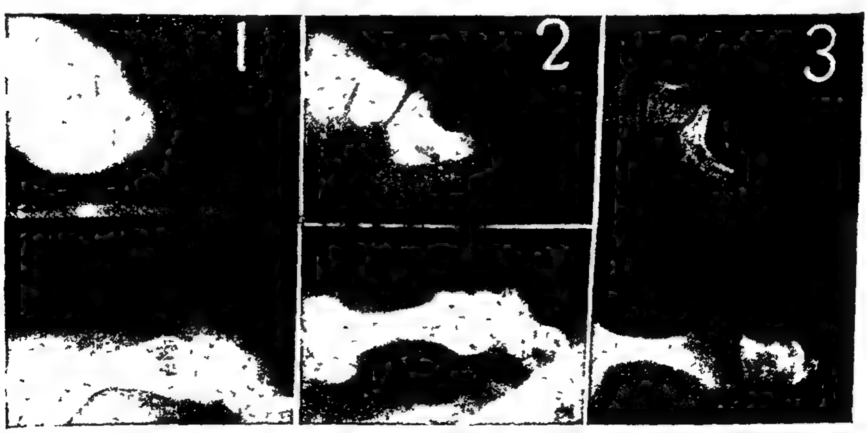

FIG 180. HELOMA DURUM ON DISTAL END OF TOE (1) Contracted toe, (2) exostosis, (3) extreme plantar flexion of distal phalanx—middle phalanx forced dorsally.

TABLE 2

Type of Procedure	Number of Digits	Time to Correct	Per Cent Recurring in Two Years
(1) Heloma prophylaxis	100	3–9 months	75
(2) Injection of:			
Procaine	15	2–3 weeks	35
Saline	15	2–3 weeks	35
(3) "Button hook" technique	104	2–3 weeks	25
(4) Exostectomy	60	2–3 weeks	60
(5) Head of proximal phalanx			
a. Fowler	85	2–3 weeks	None, time not given
b. Austin	107	2–3 weeks	15
(6) Resection of mid-phalanx (Austin-Ressel procedure)	200	2–3 weeks	0

HELOMA MOLLE (Fig. 181)

Interspace between Fourth and Fifth Toes. Impingement of tissue and frictional reactions caused by juxtaposition of the head of the proximal phalanx of the fifth toe with the base of the proximal phalanx of the fourth toe create heloma molle on contiguous sides of the toes involved. A similar situation develops in cases of juxtaposition of the head of the proximal phalanx with the head of the fourth metatarsal. In these cases the heloma molle is usually situated deep in the web and over the head of the fourth metatarsal (Fig. 182).

Use may be made of surgical correction, using the Key procedure. The toe-webbing procedure is of dubious value, and under no circumstances should the fourth toe be webbed on a higher level than the level the fifth toe would

FIG. 181. HELOMA MOLLE—INTERDIGITAL

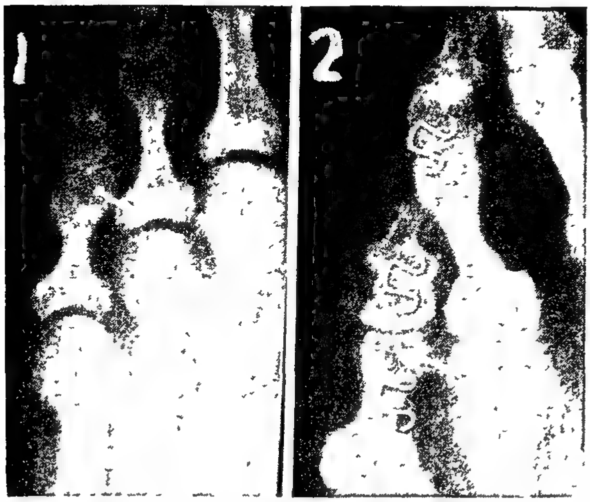

FIG 182 HELOMA MOLLE—SHOE RESTRICTION (1) Inter-digital heloma molle—juxtaposition of head of proximal phalanx of fifth toe with shelf-like base of proximal phalanx of fourth toe. (2) Inter-digital heloma molle—juxtaposition of head of proximal phalanx of fifth toe with head of fourth metatarsal

assume in a standing position If this is done, there is sure to be a recurrence of the heloma molle at a new location, usually near the fifth toe nail, as a result of the frictional problems that evolve.

Interspace between Toes other than the Fourth and Fifth (Fig. 183). Whenever inter-phalangeal joints are in precise juxtaposition, there is a possibility of heloma molle formation if unusual pressure is created This condition is frequently encountered between the third and fourth toes and between the second and third toes

Heloma molle occurring between the great toe and the second toe are usually the result of juxtaposition of the terminal process of the distal phalanx of the great toe and the inter-phalangeal joint of the second toe

HELOMA VASCULARE

Plantar Aspect beneath First Metatarso-phalangeal Area. Attention is drawn to the possible etiology of heloma vasculare in the above-mentioned location In a few cases, osteochondritis of the sesamoid bones has been described as the predisposing factor In other cases, a concession is made to the length pattern of the metatarsal bone in which the first metatarsal bone is as long as or longer than the second In this situation, transfer of body weight over these long elements creates unusual frictional conditions Surplus power of the peroneus longus muscle may also divert excess pressure at this location.

TYLOMA

A plantar callous situated under the heads of the metatarsals is definitely related to the length pattern of the metatarsals, with subsequent weight transfer, which creates unusual friction conditions under the long metatarsal bones. Prominent metatarsal heads due to contracted toes are also responsible for excrescences on the plantar aspect of the foot. The radiograph provides an excellent means for appraisal of this condition.

FIG. 183. HELOMA MOLLE—BETWEEN GREAT TOE AND SECOND TOE. Juxtaposition and crowding situation.

SUBUNGUAL EXOSTOSES

Exostosis formation originating on the dorsal aspect of the distal phalanx of the great toe creates a painful problem because it develops subungual impingement (Fig. 184). It is commonly caused by the trauma resulting from an object dropping on the great toe. On surgical exploration it is frequently found that the tumorous formation is much larger than the radiographic impression would suggest because of the areas of cartilaginous tissue that has not become calcified. Kurtz reported on a total of 102 cases, of which 100 were successfully treated by surgery. In one of his case reports he comments, "It seems almost unbelievable that someone, in eight years' time, had not radiographed the toe or awakened to the realization that it was not a nail condition."

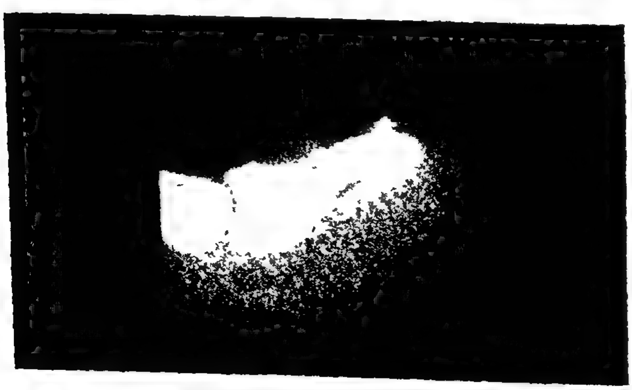

FIG. 184. SUBUNGUAL EXOSTOSIS.

FIG 185 INJECTED BURSAE—RADIO-OPAQUE MEDIA
(Courtesy of Dr R. E Owens)

Radiographic Features

(1) The lateral view discloses that the outline of the exostosis is directed dorsally under the nail.

(2) The dorso-plantar view demonstrates an area of increased density on the distal phalanx, outlining the base of the exostosis

(3) The lateral position of the exostosis may sometimes be visualized in the dorso-plantar view

INTER-DIGITAL SINUS

As a result of chronic irritation of the bone impingement of the soft tissues and the invasion of bacterial infection, a sinus tract occasionally develops beneath heloma molle Radiographic inspection may be achieved by the introduction of a radio-opaque medium such as iodized oil into the tract prior to performing the radiograph, using the soft-tissue technique. This practice is resorted to in chronic problems when surgery will follow.

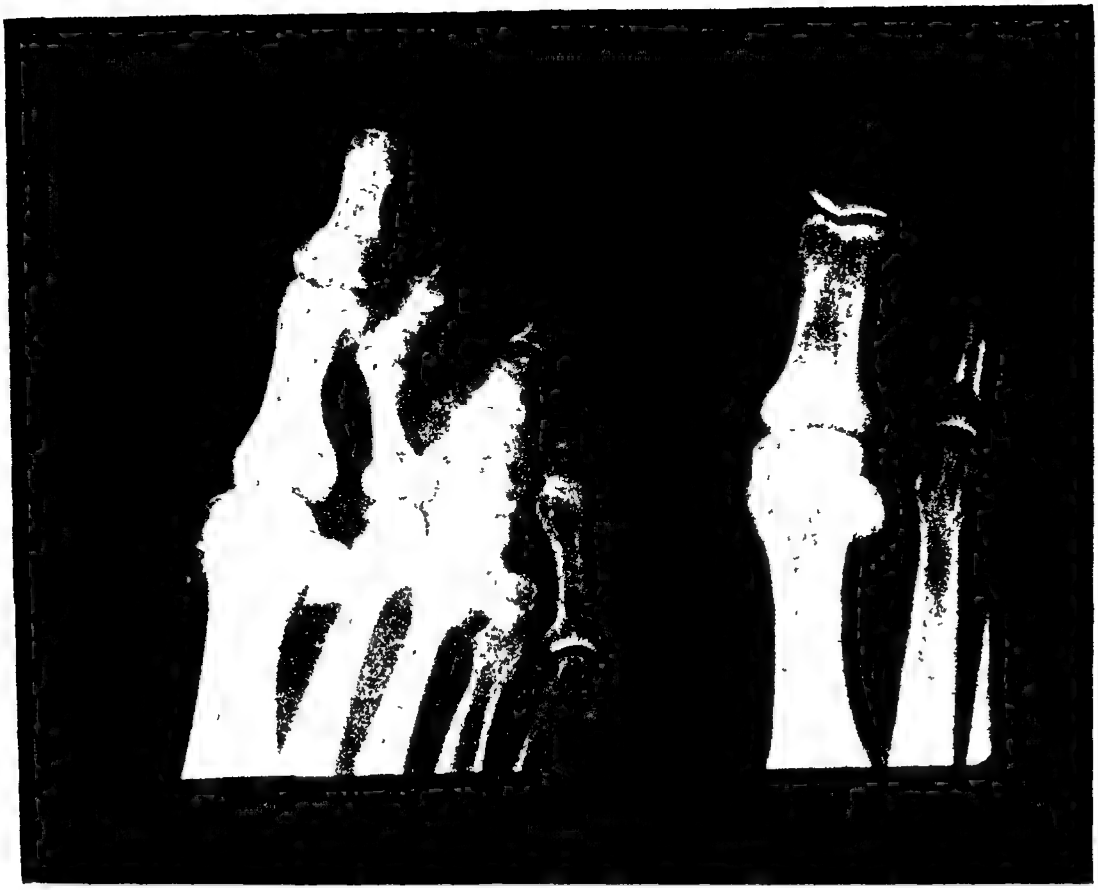

Fig. 186 Calcified Bursae

Fig 187. Acute Bursitis

Fig. 188. Infected Bursae.

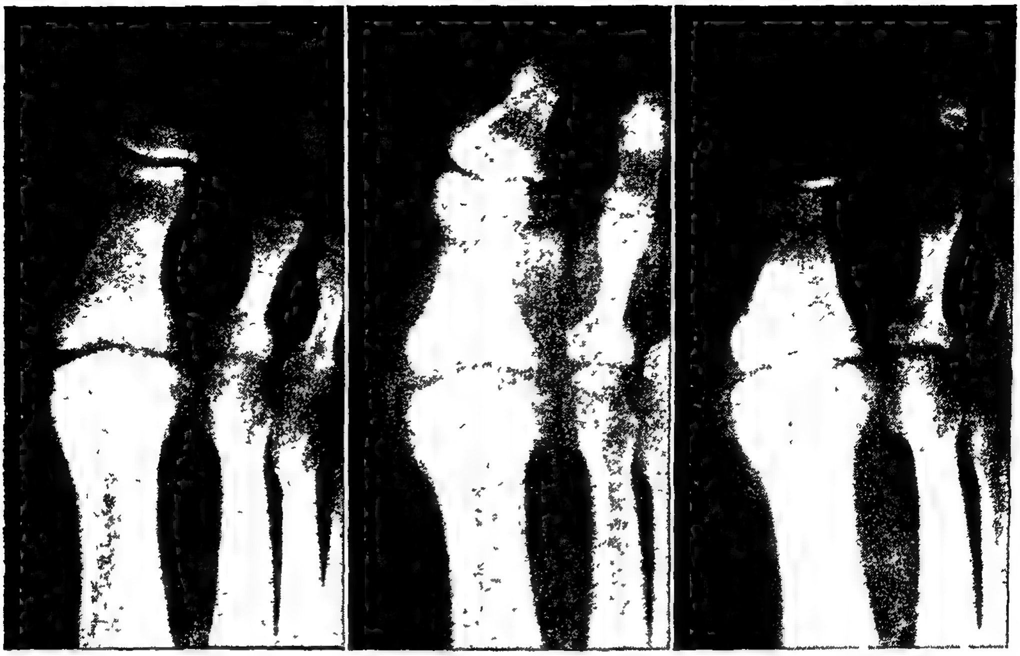

Fig 189. Osteomyelitis—Diabetic
(Courtesy of Dr. L A Walsh)

Fig. 190. Osteomyelitis—Diabetic.
(Courtesy of Drs. William and Anthony Sindoni)

BURSITIS

The bursal enlargement associated with hallux valgus may become a chronic problem which can be investigated by the injection of a radio-opaque medium so that the extent of the lesion may be studied on a soft-tissue radiograph. Owens has performed an excellent visualization of this problem which has elucidated the surgical approach needed (Fig. 185). Instances of calcified bursae have been identified radiographically (Fig. 186).

Chronic hallux valgus is responsible for the counter-pressure that creates acute bursitis (Fig. 187). In some cases the bursae may be infected (Fig. 188).

Circulatory embarrassment concomitant with diabetes may lead to bone necrosis and in some cases gangrene may follow (Figs. 189, 190).

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Significant Foot Bone Anomalies

At least twenty-five different accessory bones have been identified within the foot structure. For the most part these bones have little practical significance. However, some of these ossicles associated with functional deficiencies may be confused with fractures and have medico-legal significance. In an earlier chapter, exceptional bone shapes and bone variations resulting from functional stress were discussed in relation to foot fault syndromes. The present discussion will deal chiefly with occasional bones. Dwight classifies these bone anomalies into four general categories: (1) increase in number of bones because of persistence of elements in the embryological foot, (2) decrease in bones because of the union of elements, (3) processes not usually found, and (4) departures from the usual relations of bones.

During routine inspection of a radiograph, every supernumerary bone should be classified as to its importance, but those that are only of medical curiosity, such as the multiple distribution of sesamoid ossicles under the metatarsal heads, should be discounted unless a symptomatic problem is present in the area Attention should be fixed on those variants that create foot problems Those most frequently encountered will be discussed here

TIBIALE EXTERNUM (Fig. 191)

In cases of mid-tarsal fault, the navicular bone is the subject of careful clinical inspection, in view of the alterations of its shape. In such an evaluation, one must be careful to take into account the effects developed by a common accessory bone, the tibiale externum In many cases, a fusion which may create a protruding tuberosity or even a hook-like projection may exist More often the tibiale externum exists as a separate ossicle situated posterior and medial to the tuberosity of the navicular bone as visualized in the dorso-plantar view. The lateral view indicates that the ossicle lies posterior and plantar-wise to the tuberosity of the navicular. This ossicle is found as an unilateral entity as well as a bilateral one.

The extreme prominence of this bone may lead to irritation of the superficial structures by shoe pressure, and adventitious bursae sometimes develop. Corrective appliances are likewise irritating, and thus the true purpose of the device may be thwarted

The tibialis posterior tendon follows a normal course and attachment in this area and so, as a result of the presence of this anomaly, may lack its normal force and direction in supporting and moving the navicular.

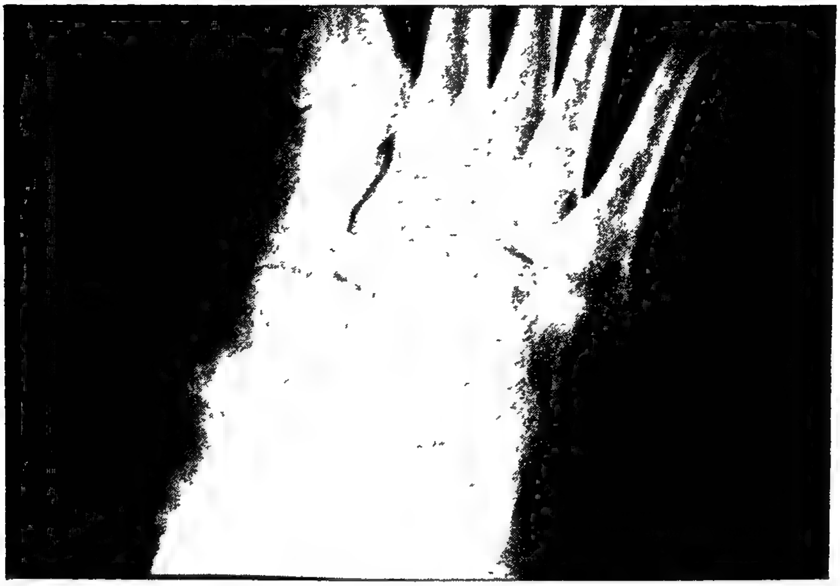

FIG 191. TIBIALE EXTERNUM

Fracture of the tuberosity of the navicular may be mistaken for a tibiale externum or vice versa. Although a somewhat irregular margin may be presented by the tibiale externum where it is in apposition with the navicular bone, the differentiation should be amply supplied by other distinguishing characteristics of fracture, such as marginal cortex, dimineralization, etc Yale obtained a favorable verdict in the Supreme Court of Connecticut in just such a case.

OS TRIGONUM (Fig. 192)

The posterior tubercle of the talus is a well-established anatomical landmark, and at this site an accessory ossicle known as the os trigonum is often found Triangular in shape, the bone may vary in size to a considerable degree It may be fused to the tubercle to create an extended elongation to the bone. It apparently serves no useful purpose except to prevent lateral slipping of the flexor hallucis tendon

From the functional standpoint, a great overburden is created when the calcaneus everts and the talus rotates in its seating The posterior tubercle is the site of considerable stress, consequently, it seems highly plausible that reactive calcification might occur in the elements involved in this reaction Interland, although at a loss for an explanation, has directed attention to innumerable instances of large os trigona and posterior tubercles in cases of arch defect.

The matter of differentiation of a fracture of the posterior tubercle of the talus from os trigonum follows the usual characteristic findings It has been our experience that fracture of the posterior aspect of the talus involves a more extensive area than the tubercle

OS PERONEUM (Fig. 193)

The peroneus longus tendon follows an extended course under the cuboid bone and across the foot to its insertion. The os peroneum is situated in the tendon and may provoke symptoms if it is located under the cuboid bone, at which times

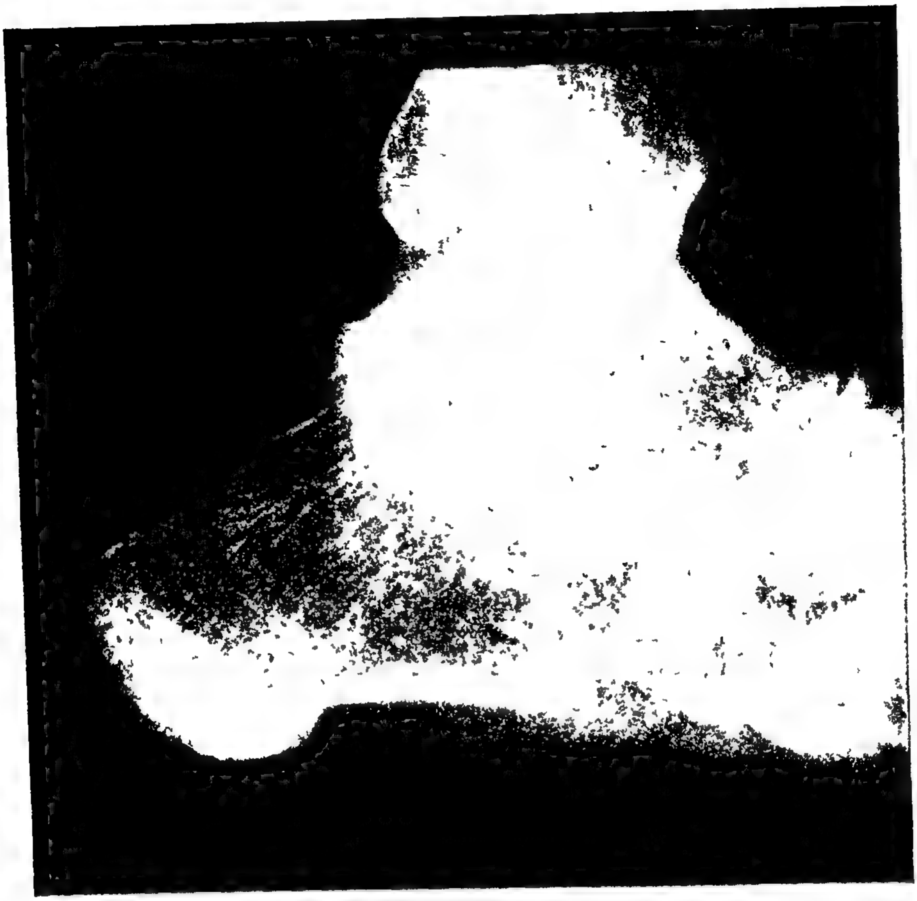

FIG 192. OS TRIGONUM

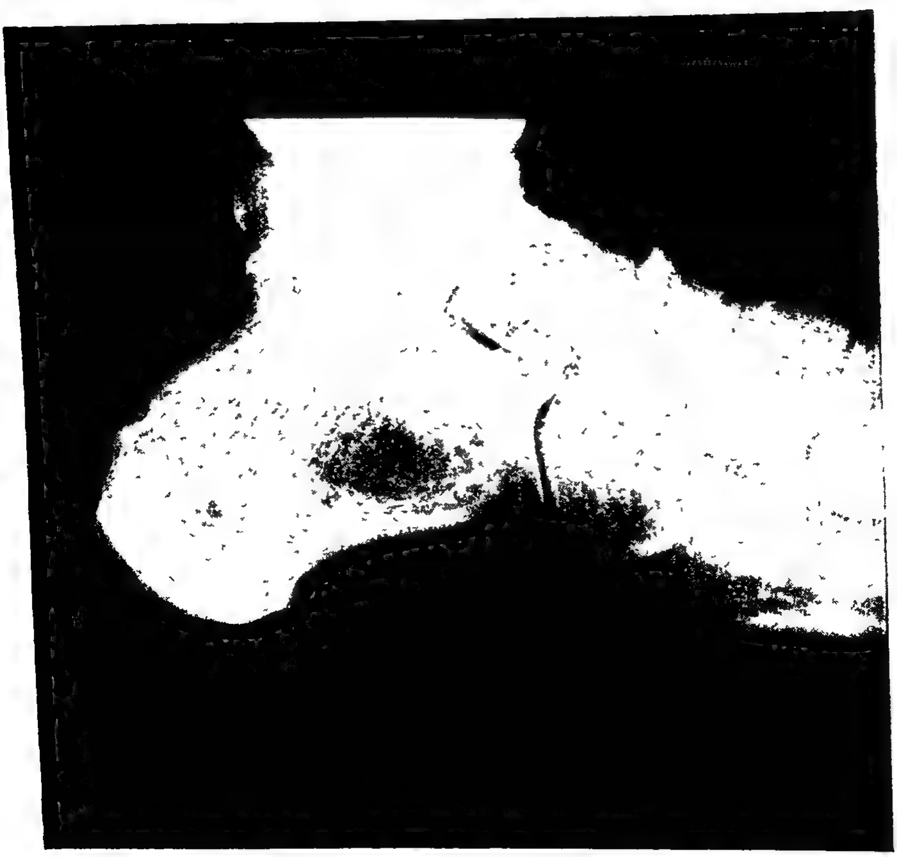

FIG. 193 OS PERONEUM

an osteochondritis of the bone may occur. Bursae may form, with the attendant symptoms. If the ossicle does not occupy a position that interferes with function or weight distribution in the foot, it may go unrecognized and be entirely asymptomatic The lateral radiographic view will demonstrate the profile and the dorso-plantar view, and the side-to-side placement

OS INTER-METATARSEUM (Fig. 194)

This ossicle is a small bone, either round or rice-shaped, lying in a dorsal position at the interspace between the bases of the first and second metatarsal bones, adjacent to the medial cuneiform bone. Dwight claims that it is found in only 10 per cent of cases and that it is not easily visualized on the radiograph because of its superimposition over a number of conflicting images It has been our experience that this ossicle may be easily identified when any part of it lies in the interspace.

Frequently, an area of increased density caused by the image of a calcified metatarsal branch of the dorsalis pedis artery will be visualized in this location. The pipe-cleaner-like appearance of this image will distinguish it from the dense and regular os inter-metatarseum

This bone is not likely to cause functional foot disorder except in cases where it is fused to the base of the second metatarsal or adjacent bones

FIG 194 OS INTER-METATARSEUM.

FIG. 195 METATARSO-CUNEIFORM WEDGE—DORSO-PLANTAR VIEW

METATARSO-CUNEIFORM WEDGE (Figs. 195, 196)

The novice is likely to mistake the overlapping images of the anterior aspect of the medial cuneiform over the base of the first metatarsal found in the normal foot for an accessory bone because of its wedgelike shape This appearance is visualized only in the dorso-plantar view, and examination of the lateral view quickly dispels any idea that an accessory bone is present

In the lateral view, the true metatarso-cuneiform wedge is visualized at the dorsal aspect of the first metatarso-cuneiform joint and presents an unmistakable wedge-shaped appearance The dorso-plantar view accentuates its outline and appearance

This bone is rare but provokes symptoms resulting from shoe irritation over its prominence.

FIG 196. METATARSO-CUNEIFORM WEDGE—LATERAL VIEW.

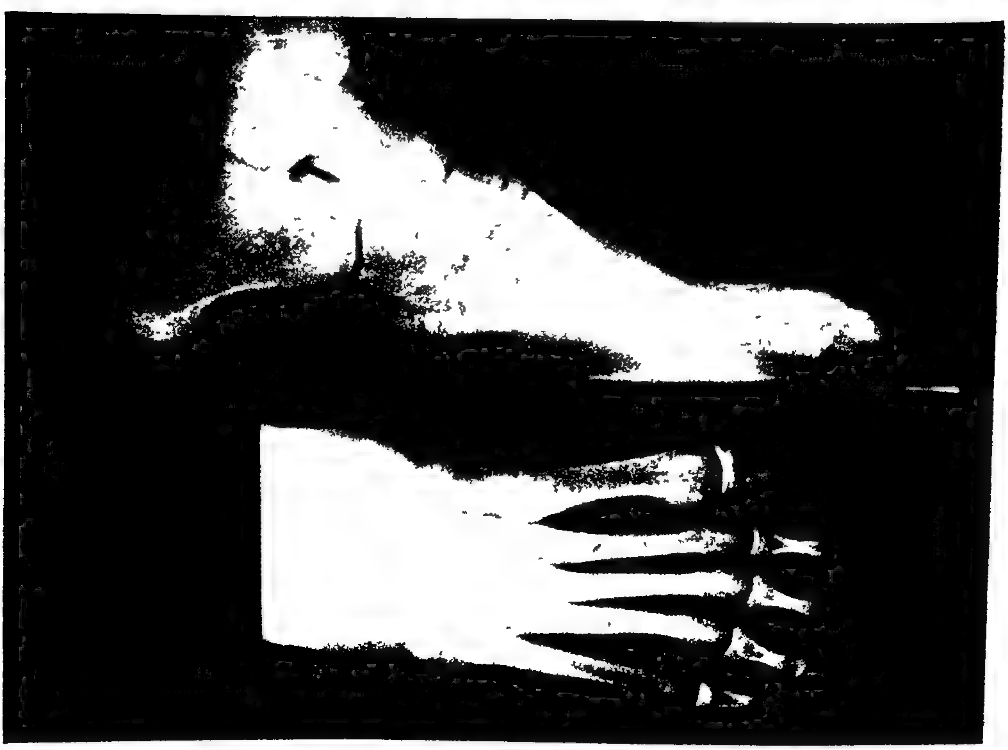

FIG. 197. OS VESALIANUM.

Fig. 198. Os Fibulare

Fig. 199. Os Tibiale

OS VESALIANUM (Fig. 197)

One of the most controversial accessory bones, the vesalianum, is situated at the posterior and inferior aspect of the base of the fifth metatarsal bone. Since the base of the fifth metatarsal is frequently fractured and fails to establish union, an extra portion of bone that is definitely ruled out as an accessory bone is often established. In young subjects, the epiphysis of the base of the fifth metatarsal is situated at the location of the accessory bone, and it is difficult to determine whether epiphysis or an accessory bone is present. In the adult foot, when we find an ossicle with smooth contours and cortex density in this location, we are inclined to accept it as the vesalianum. This is particularly true if other ossicles and bone variations are present in the same foot, since that fact would establish the trend for accessory bones.

OS FIBULARE (Fig. 198)

This ossicle is situated at the inferior aspect of the fibula at the talo-fibular articulation It may be of such a substantial size as to be easily confused with a fracture of the tip of the fibula In cases of fracture, there should be a defect in the fibula to match the fractured fragment In cases of os fibulare, no defect exists in the fibula and the os fibulare is smooth in contour with no serrated fracture line.

In two cases the writer has discovered os fibulare in traumatic cases

OS TIBIALE (Fig. 199)

The os tibiale is a well-developed ossicle situated at the inferior aspect of the medial malleolus, at the very tip of the tibia. Like the os fibulare, the os tibiale might easily be mistaken for a chip fracture The same differentiation should be made.

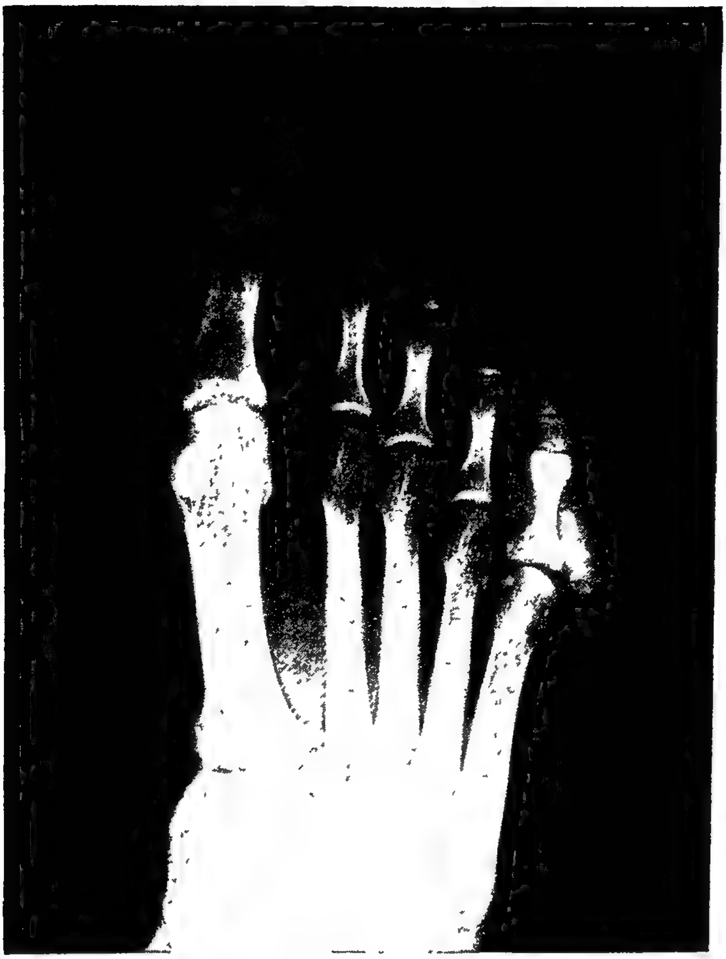

FIG 200. POLYDACTYLISM

POLYDACTYLISM (Fig. 200)

Over-segmentation of the primary anlage of the fetus is responsible for the production of extra phalanges, vestigial metatarsal bones, anld other additional bones. These bones frequently cause trouble by crowding the foot in a conventional shoe. Careful roentgen evaluation of the problem should be made, since more than one problem may be involved which might be eliminated by surgery.

SYNDACTYLISM (Fig. 201)

Congenital malformations of syndactylism are significant when they interfere with the function or freedom of foot structure Interference in the false articulation between metatarsal bones in the forefoot may be a significant aspect of this type of problem. Various combinations are found, according to the act of fate.

Synchondrosis is frequently encountered in a bridge between the navicular and calcaneus and is of orthopedic significance

FIG. 201. SYNDACTYLISM.
(Courtesy of Dr C. E. Krausz)

FIG 202 APLASIA.

APLASIA (Fig. 202)

According to Caffey, entire bones may fail to form in the membranous stage during fetal life This, of course, is the basis for absence of body parts, particularly absence of toes. These problems present a need for specific orthopedic supervision and the construction of adequate prosthetic appliances.

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Chapter XI

Podo-pediatric Roentgenology

The foot of the child presents radiographic features different from those of the fully matured adult foot. At birth the basic bone shapes of the foot are fully patterned in cartilaginous tissue. This fact is not apparent in the conventional radiograph of a child at birth because there is not sufficient delineation of cartilage from the superimposed density of the skin and fascia integument to outline the pre-bone shapes. Harford prepared a foot specimen of a nine-month stillborn fetus by removing the skin integument, and this writer radiographed the foot, using soft-tissue technique. Each and every bone shape is completely demonstrated. This emphasizes the fact that dominant bone shapes are pre-determined at birth (Figs. 203, 204).

Since the conventional radiograph of a child's foot only demonstrates areas of mineralization, it might be easy to slip into the delusion that the pre-bone cartilage of the foot is a homogeneous mass that only becomes differentiated on mineralization. Every time one examines a radiograph of a child's foot, he must realize that complete bones are present in their dominant shapes, even though not visible on the radiograph.

The only evidence that may be used in radiographic appraisal is the actual areas that are mineralized specific bones It is Noback who classifies two types of ossification centers prenatally: the centric centers in which the ossification center is approximately in the geometric center of the bone or the part of the bone that the center forms, and the eccentric centers in which the ossification center appears in loci removed from the geometric center of the bone or part of the bone that the center forms. His research has placed the cuboid and talus in the classification with centric centers, and the calcaneus with eccentric centers Our study of the mineralization of these centers confirms a similar pattern of maturation At birth, therefore, in a lateral view of the foot the mineralized zones of the calcaneus and talus may be visualized, however, their related positions do not coincide with the mid-tarsal joint because of the placement of their ossification centers

According to the studies of Bruce and Walmsley, in the normal foot at birth, an inherent arched pattern is established for the foot bone In fact, they claim that arched contours are developed as early as the third month of fetal life. This arched pattern may only be observed on dissection or section of specimens, because fat-pad, fascia, skin, and other soft tissue structures frequently create a flat foot appearance of the external contours at birth.

Fig. 203 Bone Shape Pattern at Birth—Dor-o-plantar iew. 9-month still-born specimen, skin integument reoved. Note outlines of cartilaginous bones. Also, observe e relationship of mineralized zones of talus and calneus to the entire bone shape.

Fig. 204 Bone Shape Pattern at Birth—Lateral View. Note normal mid-tarsal joint line, both views.

Although the foot presents fully shaped bones at birth, and a generally arched conformation, the actual alignment may not be resolved into the proper pattern which typifies a strong adult foot for several years. The changing position of the foot during fetal development has been described in the chapter entitled "Congenital Pes Planus" (Chap IV). Arrest in the morphological progression of foot bone alignment may fix the foot in a variety of problem foot types. It is entirely feasible that the foot continues to improve its bony alignment for an undeterminate time after birth. It is a fact that faulty alignment of the child's foot may be corrected and guided to a normal adult foot (Figs. 205–207).

It takes nature 8 to 12 months to mature and coordinate the development of the infant to sustain an erect posture. During this time the process of bone growth is continually taking place, and all of the adjusting factors affecting foot alignment are in play. The position of the baby lying face-down in the crib, the mode of crawling, etc. help to mold the foot and strengthen or weaken it. The neuro-muscular system must resolve the foot into a functioning organ, and in so doing must direct the growth of the foot into a normal structure. Any inter-

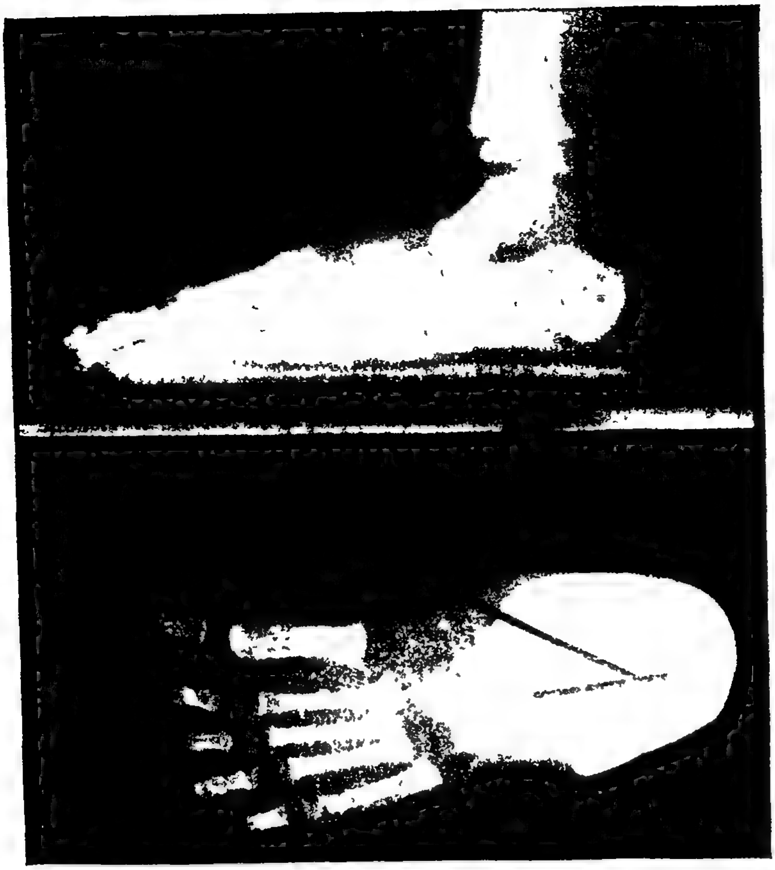

Fig 205 G J G, Foot Mal-alignment at Age 17 Mos
Note position of talus

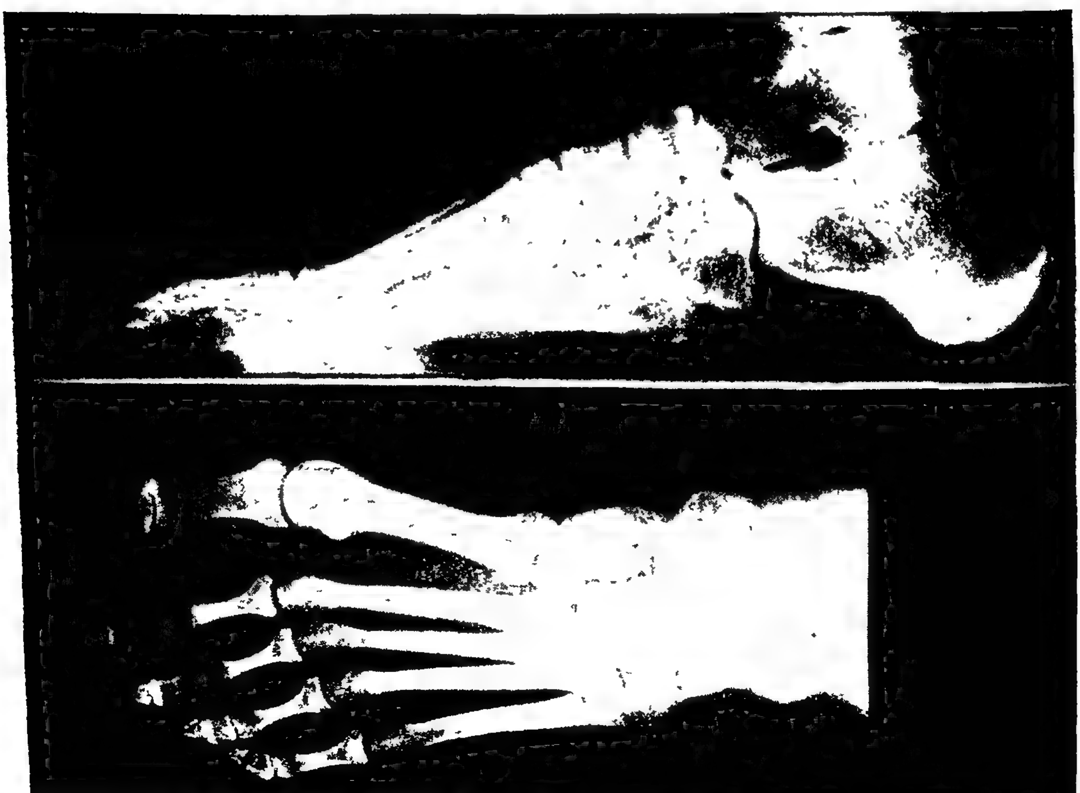

Fig 206 G J G, Complete Foot Correction at Age 17 Yrs, 8 Mos
(Same case as Fig 205)

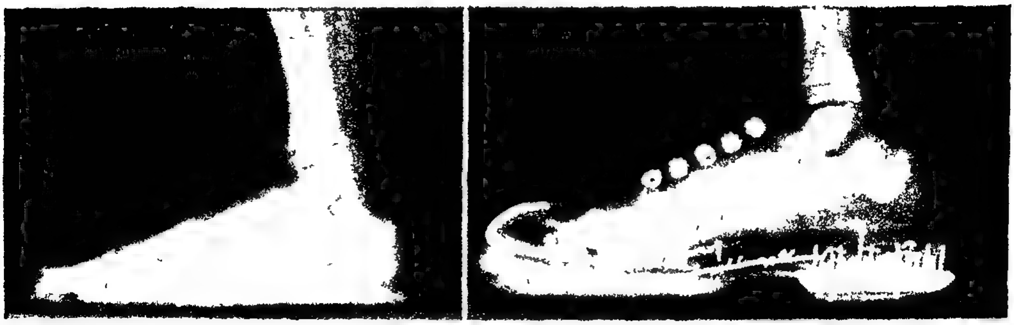

FIG. 207 G. J. G., PHASES OF APPROPRIATE TREATMENT AT AGE 2 YRS., 8 MOS. (Same case as Figs. 205, 206). Shoe modifications, 1/4 in. medial heel wedge, 1/4 in. lateral sole wedge, Thomas heel, extended counter High Dye Flexible Casting adhesive strapping.

ruption in this development will create either a deficient foot structure predisposed to fault syndromes, or an entirely abnormal foot type.

The total physical status of the infant influences the form of the foot. If the infant is rachitic, bowing of the extremities is likely to occur with attendant faulty foot posture Innumerable instances of general pathology may be cited in this reference. The very healthy infant whose weight becomes excessive is one of today's great factors in patho-anatomic foot disorder. If the inherited foot pattern of the infant is weak, the impost of excess weight during the first years of standing invariably damages the structural status. In the opinion of the author, a great percentage of the acquired foot problems are instigated at this time and become amplified to the impairment of function at some later stage of the development of the individual.

GENERAL CONSIDERATION OF RADIOGRAPHIC IMPRESSIONS

The radiographic features that characterize the position and relationship of the infant's foot from birth until two years of age consist of the following:

(1) The talus in which the distal portion and body of the bone is mineralized first, to the exclusion of the postero-inferior aspect.

(2) The calcaneus with mineralization of the body of the bone and a lack of deposition in the anterior process.

(3) Centric mineralization of the cuboid

(4) The head of the talus, seemingly in the dorso-plantar projection, advanced beyond the anterior process of the calcaneus This is accentuated because of the location of the mineralized ossification centers

(5) The talus should be closely aligned with the calcaneus as medial rotation of the bone would be demonstrated by a wide separation of the bones

(6) The lateral projection discloses an apparent advance of the talus beyond the mid-tarsal joint line This appearance is due to the mineralization of the distal portion of the talus, and the late mineralization of the anterior process of the calcaneus

(7) The cuboid is present in 50 per cent of all feet at birth and in 90 per cent by the sixth month, according to Stuart Its centric ossification and mineralization places its position far removed from the anterior portion of the calcaneus

FIG. 208. MULTIPLE NUCLEI FOR OSSIFICATION OF CUNEIFORM
(Courtesy of Dr. George Wright)

FIG 209. IRREGULAR OSSIFICATION OF CALCANEAL TUBEROSITY

Fig 210 Normal Foot—Age 6 Yrs.

In the lateral projection, this creates an excessive width that emphasizes the need for caution in using the mid-tarsal joint line as a criterion of talo-calcaneal position

One must be very circumspect in the consideration of the foot of a child from the age of two through five years. Innumerable variations in the ossific centers occur, and the lack of substantially developed bones is likely to misrepresent the true alignment status of the foot The medial cuneiform bone may develop from multiple ossification nuclei, thus presenting a confusing appearance (Fig. 208) Gross irregularities in outline of the mineralized zones of the plantar tuberosities of the calcaneus seem to indicate a malformed bone, but are quite innocuous (Fig 209) The rate of bone growth varies considerably in the foot between the tubular long bones and the round bones. It has been estimated that at birth the forefoot is relatively 6 per cent longer than in the adult foot This is a consideration By the end of the fifth year all ossification centers, both primary and secondary, have put in their appearance, with the exception of the epiphysis of the calcaneus.

During the ages of five through twelve years, the foot makes a rapid maturation and the radiographic features take on sufficient proportion to be of value in the interpretation of foot patho-anatomy It should be noted that the distal end

of the metatarsal shaft and the articulating phalanx are widely separated, and this indicates that mineralization and ossification are incomplete. In spite of this pre-bone joint zone, the foot is fully capable of sustaining the stresses imposed at the metatarso-phalangeal articulation. The final secondary center of ossification, the epiphysis of the calcaneus, occurs at the age of eight in the female and from ten to eleven in the male child. Throughout all ossification and maturation schedules, the female is accelerated in comparison with the male by approximately two years.

From the age of twelve until twenty-two in the normal individual, maturation of the entire foot skeleton is completed. The irregular bones developing from a single center gradually take their shape. The epiphysis of the calcaneus fuses with the apophysis from the age of twelve to twenty-two years while the epiphysis of the long bones fuses with the apophysis from the age of eleven to twenty-two years. Most patho-anatomy, with the exception of metatarsal disorders, may be interpreted on the same basis as the adult foot during the age bracket between twelve and twenty-two years.

Appraisal of skeletal age is but one consideration of the appearance of mineralized ossification centers and the maturation scheme. When one views the status of growth of the skeleton as projected in graph form, the curve varies in gentle peaks through the four stages that have been described: birth; two years; two–five years; five–twelve years; twelve–twenty-two years

Each stage has distinctive features The main bones of the foot receiving greatest stress—the calcaneus, talus, and cuboid—are solidly configured in the first stage. The lateral cuneiform puts in an appearance between the first 6 to 7 months Lateral transfer of forces through the foot are carried by the lateral cuneiform, and it seems logical that it should develop at this time. In the 18th month the navicular shows ossification; thus, the first stage includes the vital components of the hindfoot and mid-tarsal joint.

In the second phase, at three years, the medial and middle cuneiforms and the secondary epiphysis of the phalanges and metatarsals appear. A period of rapid growth of the foot size may fall in this period up until the age of five.

The third stage, from five through twelve years, includes the appearance of the epiphysis of the calcaneus which is the final secondary ossification center. Growth progresses at a spasmodic rate during this period, although at a relatively steady increment

The fourth stage is the stage of maturation in which final fusion occurs between all epiphyses and diaphyses.

The patho-anatomical problems that have been evaluated through-out the preceding chapters of the book have their counterpart in the foot of the child with but a few exceptions which are chiefly orthodigital problems and secondary excrescences A complete and detailed exposition of the radiographic features would be voluminous Outstanding features of the major patho-anatomical problem will be given, and the reader is advised to be practical in his assessments. Refer to each chapter which describes the adult foot problem as the podo-pediatric problem is studied In clinical practice be cautious not to depend entirely on radiographic findings but utilize every diagnostic medium available Bear

FIG. 211 NORMAL FOOT—AGE 13 YRS

in mind that in addition to the appearance of bone position as the result of incomplete ossification, the foot of the young child has not developed anatomically to the status it will enjoy when fully matured.

Radiographic Features

Normal Foot. A lateral view of the weight-supporting foot is required, although seldom achieved before the age of one year In the infant up to a two-year age bracket, the talus seems to jut beyond the anterior portion of the calcaneus This is true because the ossification occurs in the head of the talus, and there is a deficit in the postero-inferior aspect. Furthermore, there is a deficit of ossification in the anterior portion of the calcaneus. The extremely wide space between the calcaneus and cuboid is the clue to the lack of mineralization of these components If the distal portion of the head of the talus is compared to the proximal surface of the cuboid, an approximately normal mid-tarsal joint line may be estimated Although the talus seems pitched downward by virtue of its ossific proportion, it may rest in a virtually parallel plane if little overlap of the head of the talus is visualized over the anterior portion of the calcaneus.

The dorso-plantar view reveals little more than the head of the talus as it is related to the anterior portion of the calcaneus Under normal circumstances they should be closely bound The diaphyses of the metatarsals lie on their normal planes

It may be observed that there is a disproportion in the relative sizes of the talus and calcaneus with the talus seemingly of gross size. When one considers that no epiphysis has invaded the calcaneal outlines, it is easy to appreciate the apparent size difference.

In the child of two to five years the navicular and cuneiform bones ossify, adding familiar elements and bulk to the radiograph. The discrepancy in sub-talor space diminishes as the postero-inferior aspect of the talus ossifies, and the increased mid-tarsal joint space lessens as the anterior portion of the calcaneus and the cuboid increase in stature.

From five to twelve years, all bones increase in their mineralization, and the epiphysis of the calcaneus establishes a finality to the shape of this bone (Fig. 210).

The years from twelve to twenty-two merely carry through the ossification pattern to completion, unless otherwise thwarted (Fig. 211).

Hindfoot and Mid-tarsal Fault. (Figs. 212–214). In the lateral view, the talus is directed downward in pitch and overlaps the anterior portion of the calcaneus. The calcaneus is of low pitch.

FIG. 212. MID-TARSAL FAULT—AGE 2 YRS

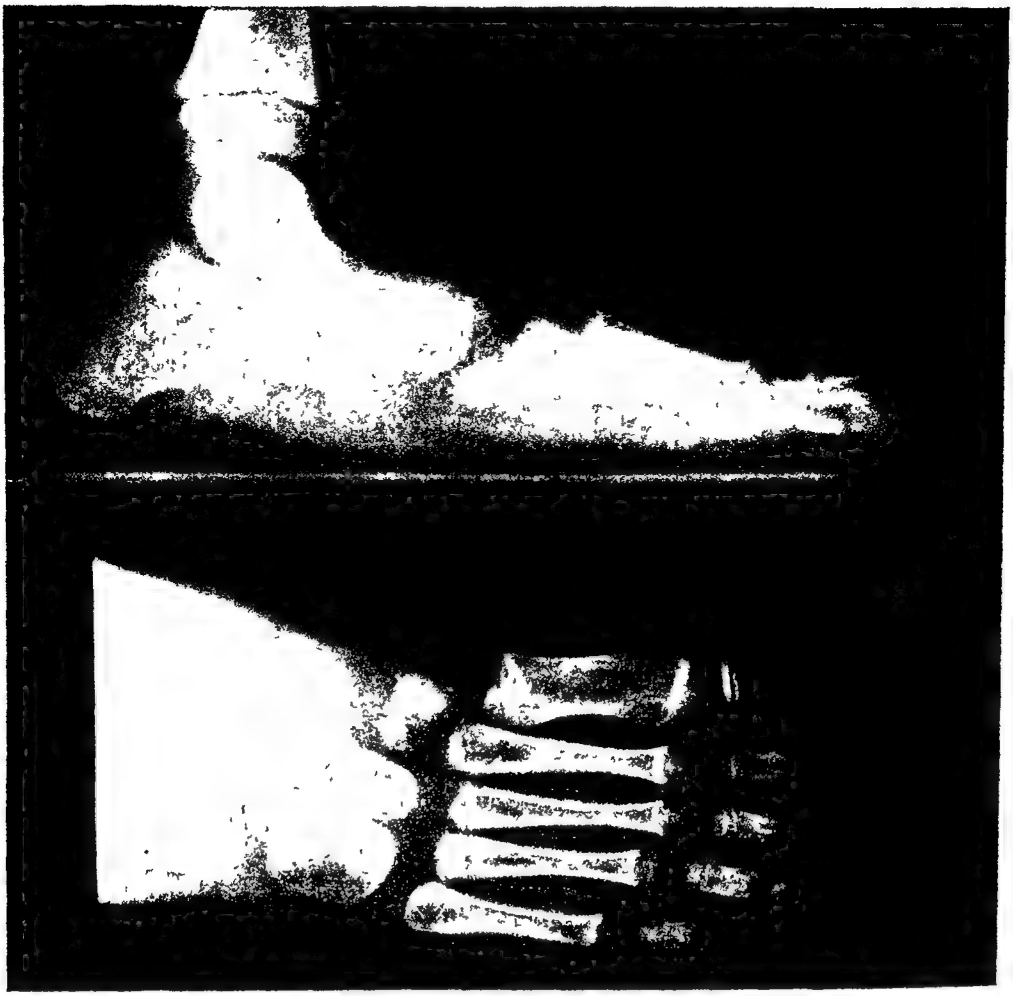

FIG 213 MID-TARSAL FAULT—AGE 8 YRS.

The dorso-plantar view discloses a loosely bound talus and calcaneus This looseness varies in degree

The forefoot status in respect to abduction, in severe cases, may be appraised On the other hand, adduction is a typical compensatory alignment

Navicular-cuneiform Fault. Late total maturation of the navicular eliminates this fault syndrome from identification except in the older child Ossification of the navicular begins at 18 months The sequence of ossification of the cuneiforms helps in the evaluation of this problem because the lateral cuneiform is first in its ossific development, followed by the middle and finally by the medial These ossification zones, when superimposed in the lateral view, help to distinguish the forward tilt of the navicular and the depression of the navicular cuneiform joint by virtue of the position of the second cuneiform

Koehler identified a condition of the navicular between the ages of five and six in which the bone appeared sclerosed, flattened and frequently fragmented (Fig 215) Much speculation has developed concerning the etiology of this condition In the opinion of this writer, irregular mineralization and maturation of a developing bone are linked with poor vascularization and persistent stress A surplus deposition of mineral salts is the physiologic reaction to stress, and

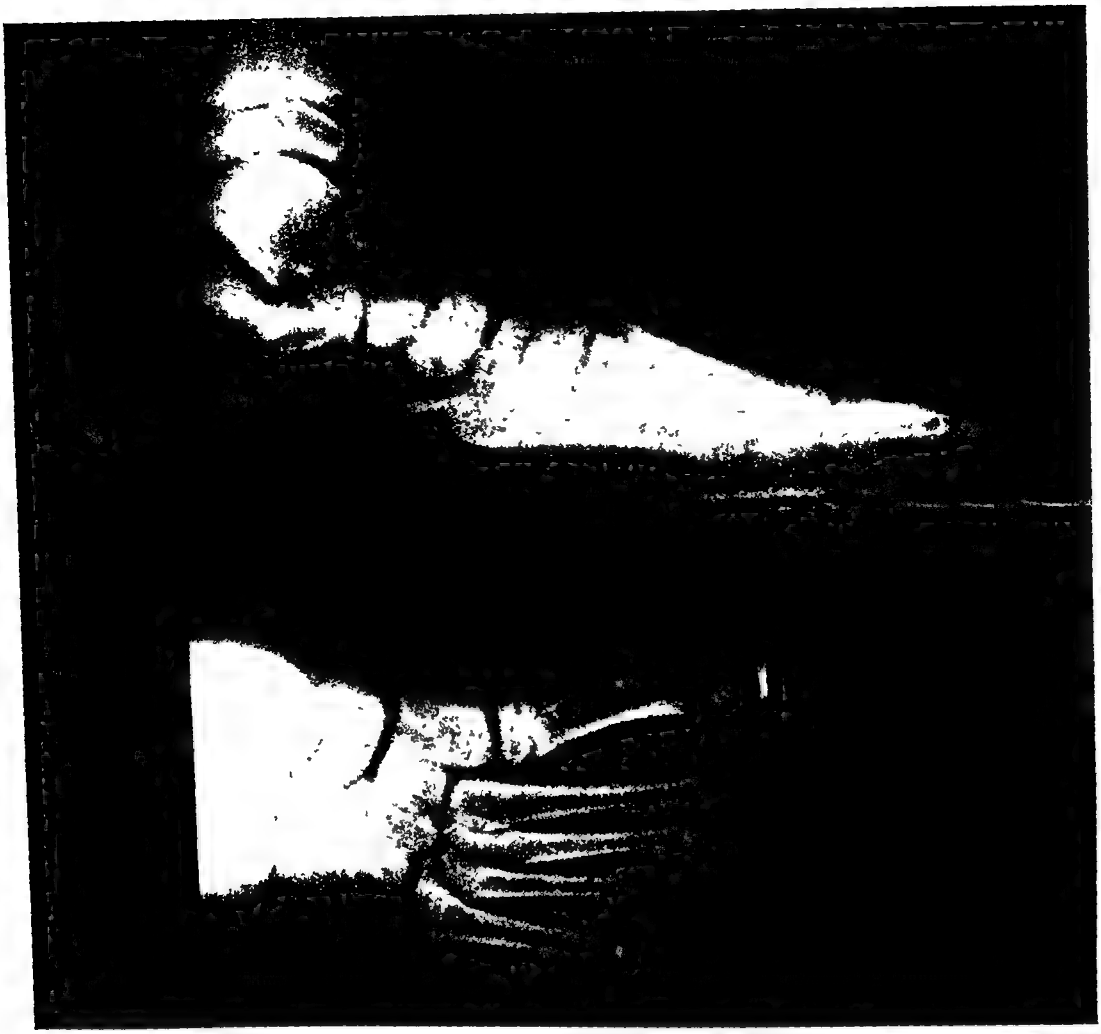

FIG. 214. MID-TARSAL FAULT—AGE 12 YRS.

under normal circumstances dissolution occurs through faulty circulation. Imbalance of these factors triggers the production of the aseptic necrosis. The condition is a clinical entity associated in many instances with mid-tarsal fault and navicular-cuneiform fault It is not unlikely that faulty alignment is a factor in the production of the precise stress pattern in a favorable host.

Calcaneo-cuboid Fault. The lack of delineation of articulation between the cuboid and calcaneus precludes identification of the usual fault features until the foot is matured

Morton's Syndrome (Fig. 216). Absence of the mineralization of sesamoid bones until the final stages of foot maturation robs the foot radiograph of the child of one of the diagnostic criteria offered by Morton

The radiograph of the immature child's foot draws attention to the fact that the first metatarsal secondary center of ossification is situated at the base of the bone rather than at the distal end as patterned in the lesser metatarsals. A relatively short first metatarsal may be discerned as soon as the distal epiphyses of the lesser metatarsals have developed The second metatarsal shaft develops a compensatory hypertrophy at an early stage. Hypermobility cannot be effectively appraised

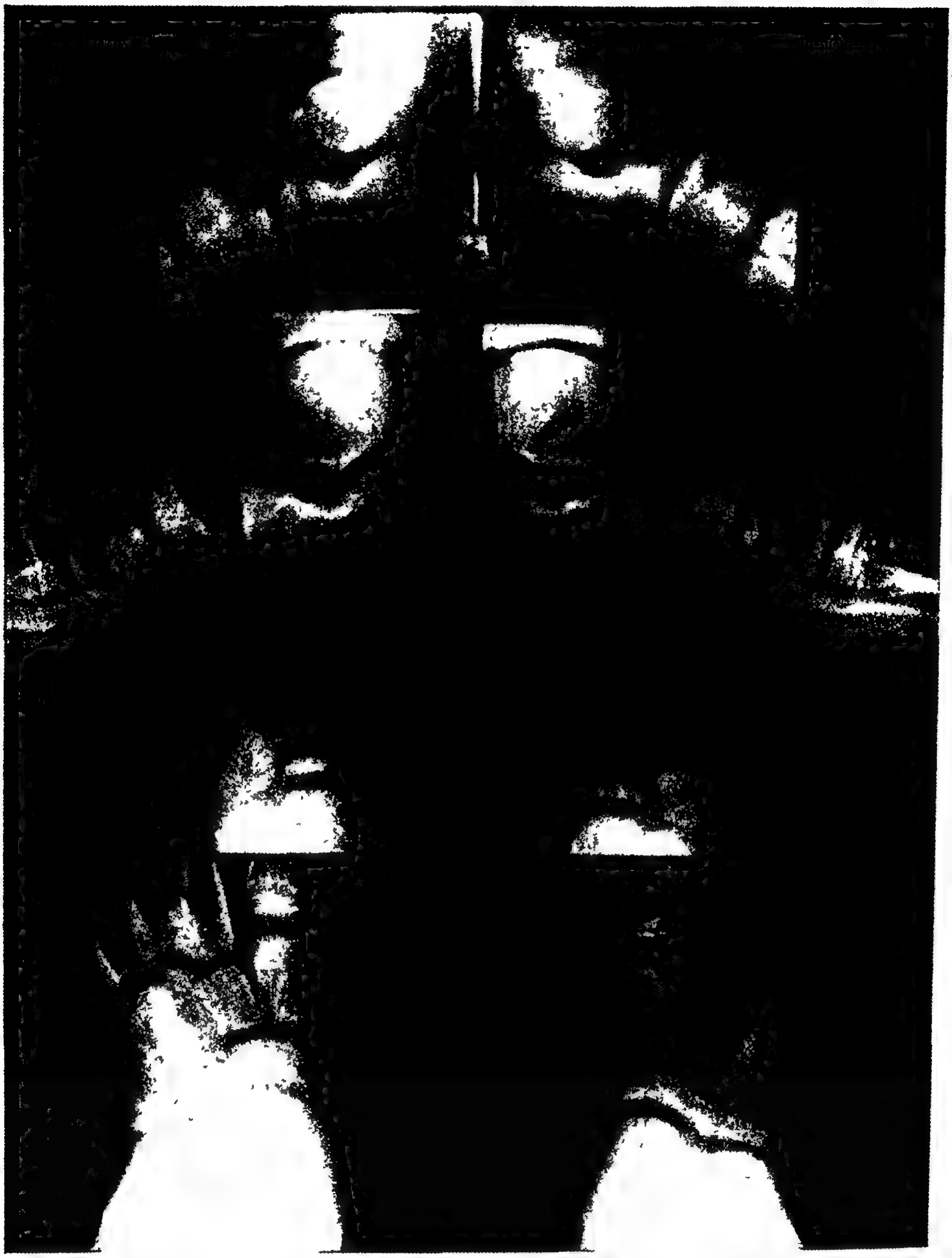

FIG 215 OSTEOCHONDROSIS OF NAVICULAR Before and after six years of foot growth.

Congenital Pes Planus. The characteristic shape of the calcaneus with its bulging contour at the plantar aspect of the anterior process identifies this foot type in early childhood. The plantigrade pitch of the calcaneus is another unmistakable radiographic feature that may be viewed in the lateral projection.

The dorso-plantar projection discloses the talus widely diverted from the calcaneus. As in the adult foot, the forefoot may be in typical abduction or compensated into adduction (Figs 217, 218).

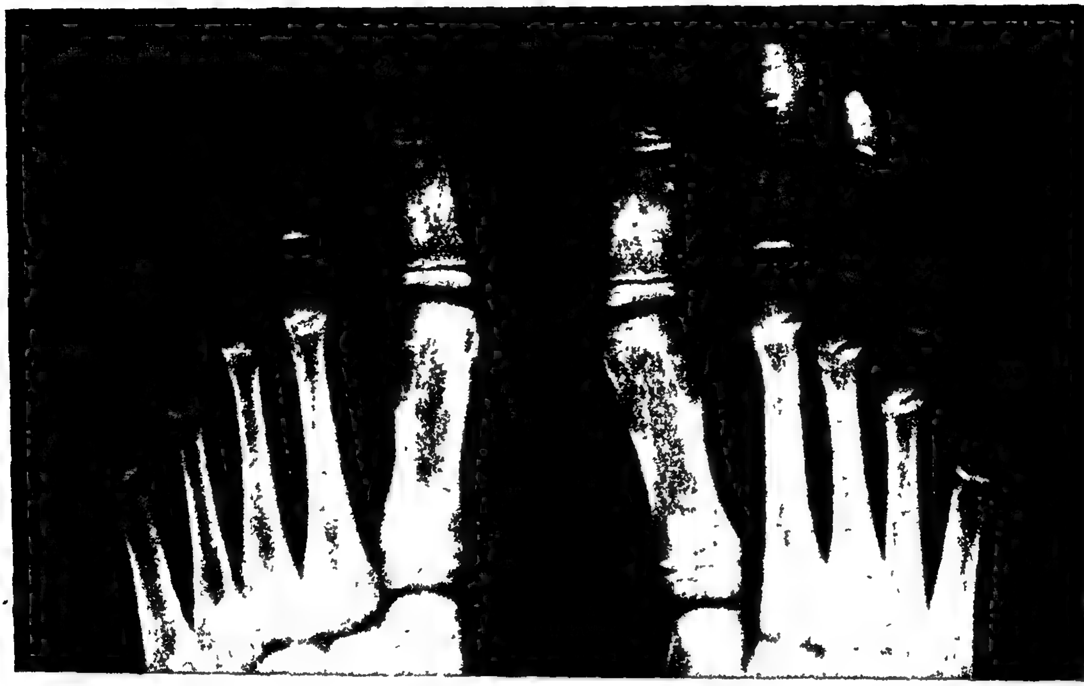

FIG. 216. MORTON'S SYNDROME.

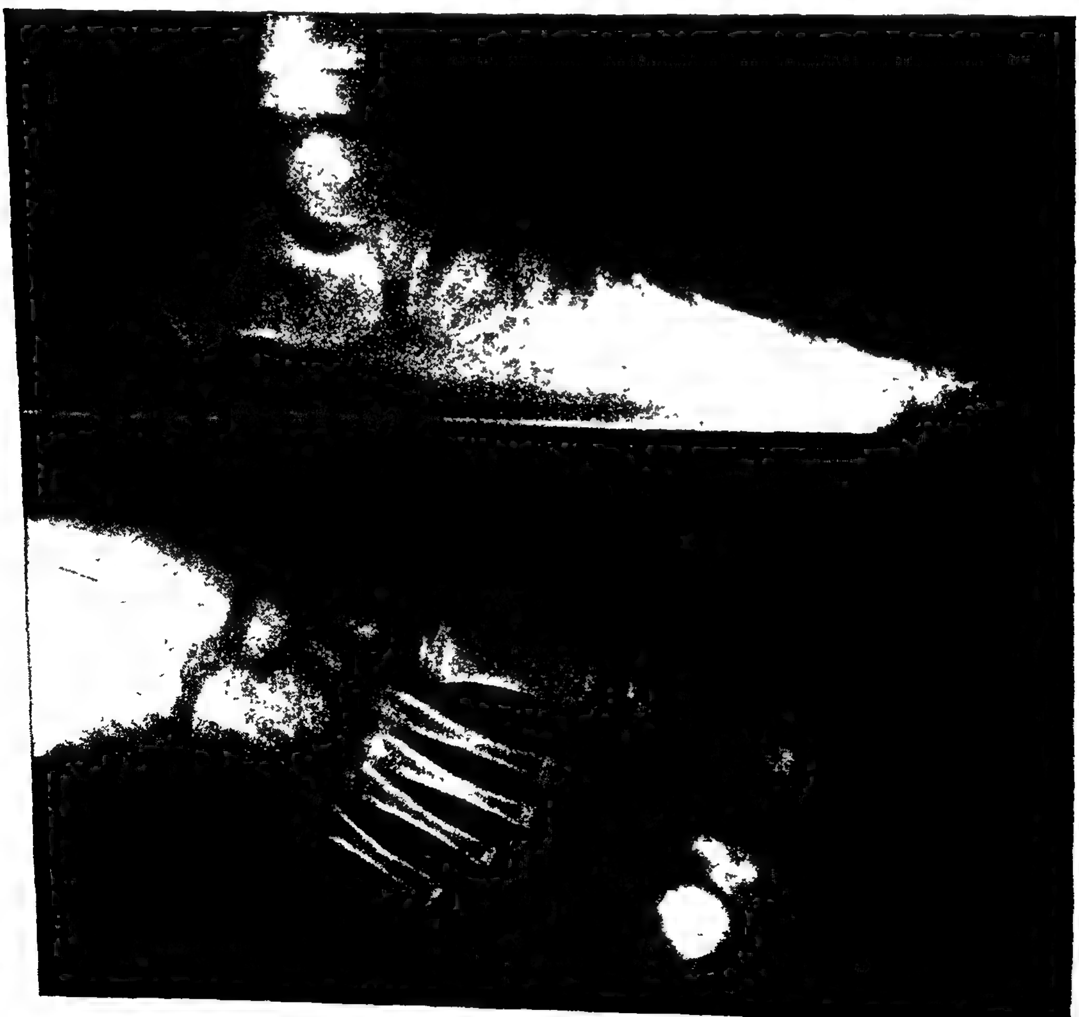

FIG 217 CONGENITAL PES PLANUS WITH ABDUCTION.

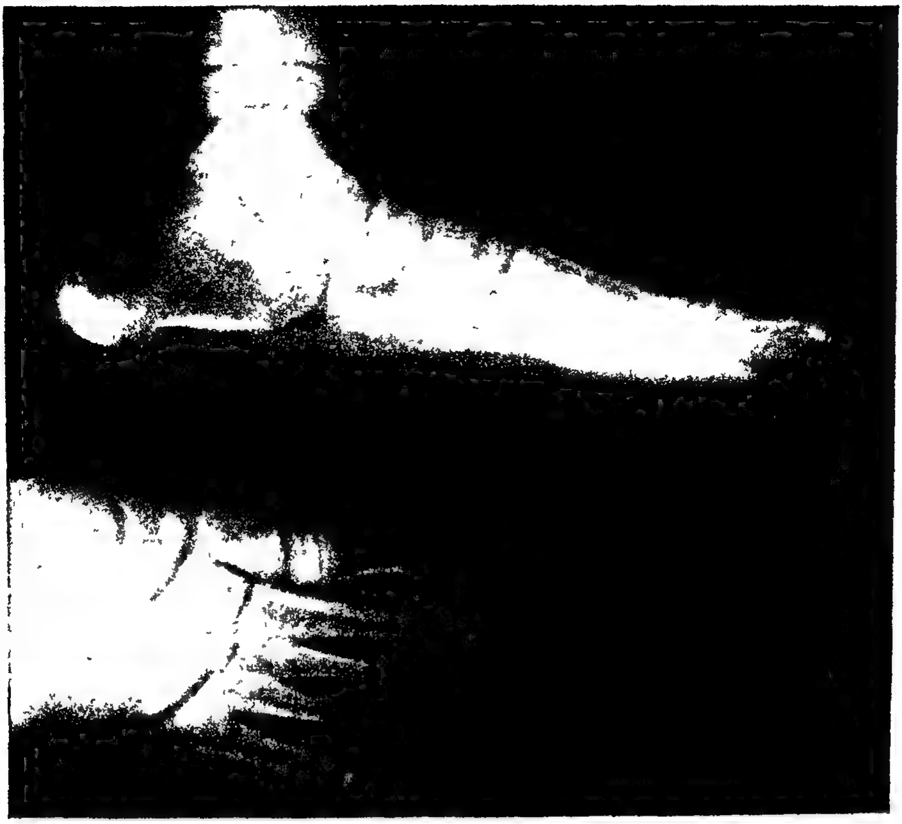

FIG. 218. CONGENITAL PES PLANUS WITH ADDUCTION.

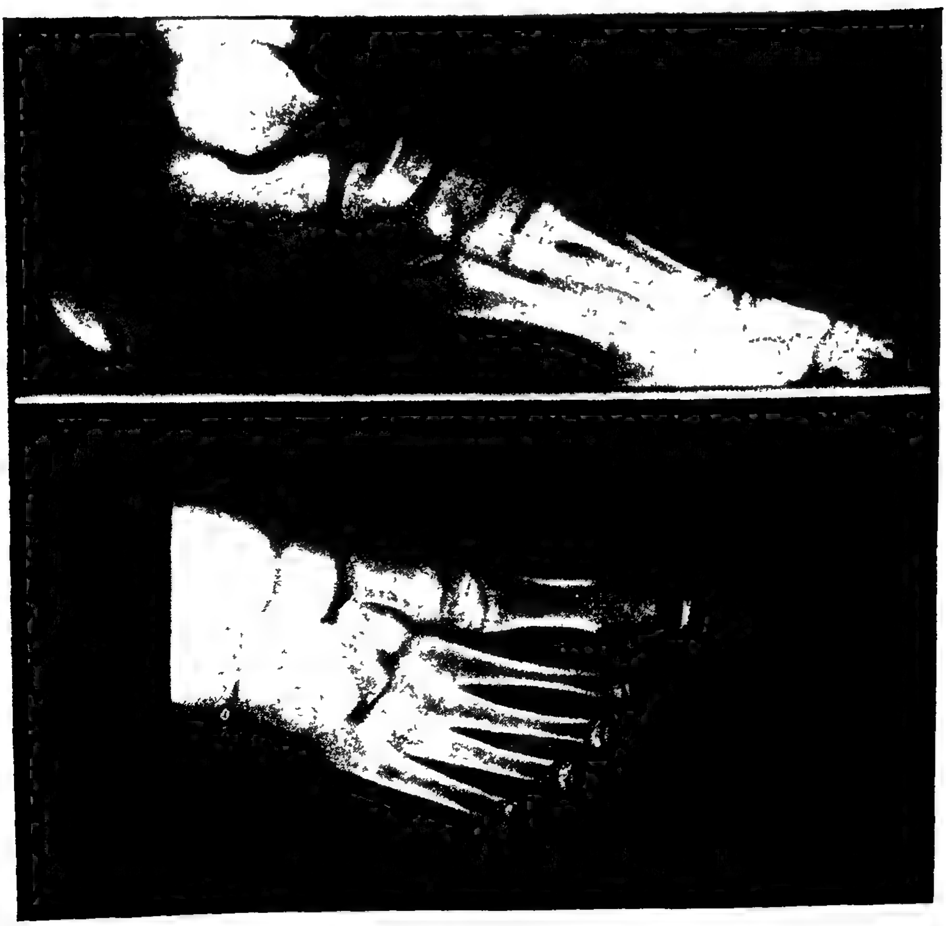

FIG 219 PES CAVUS

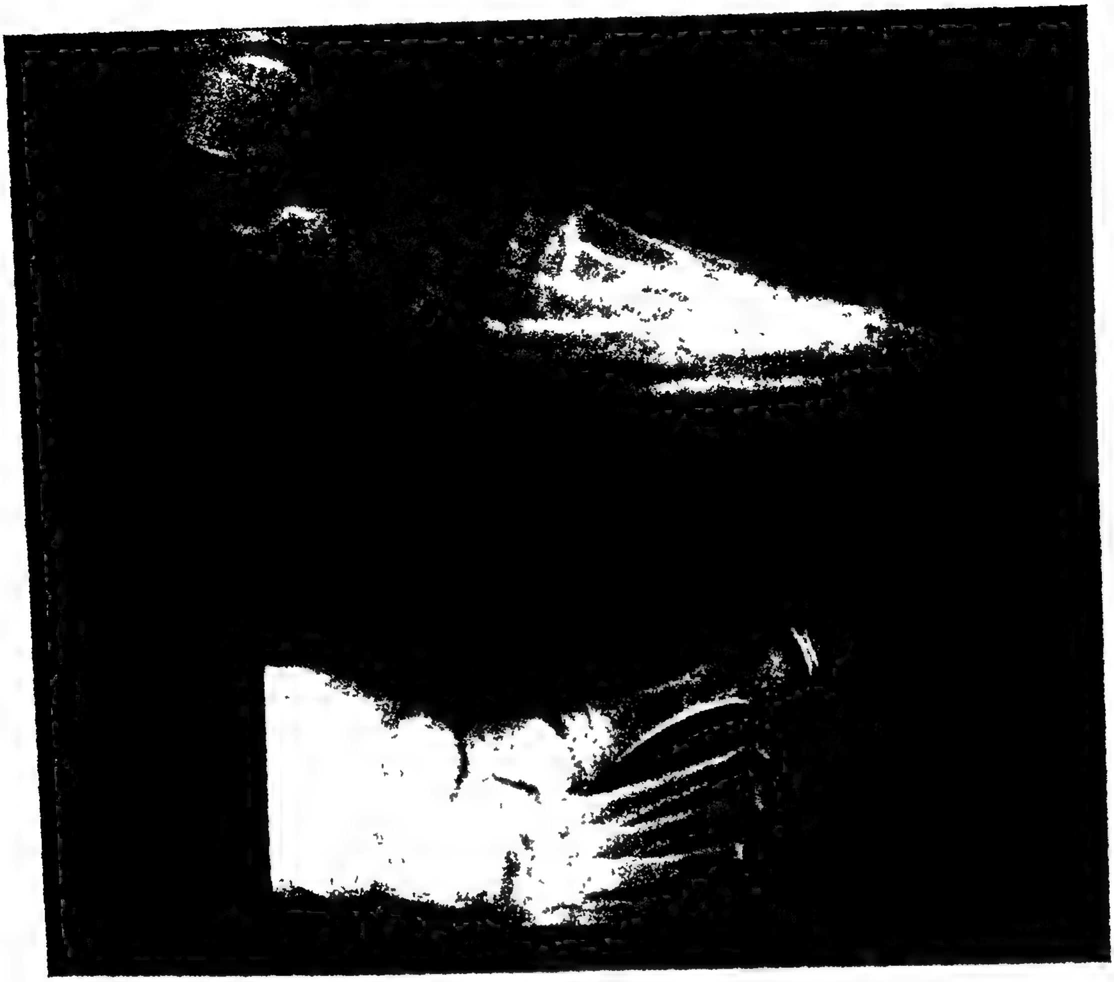

FIG. 220. PES ADDUCTUS.

Additional faults may be added to the basic congenital pes planus. This is a sorry foot condition with little chance of rehabilitation short of reconstructive surgery.

Pes Cavus. The high pitch of the calcaneus identifies this foot type in the very young foot, and the talus lies on a typical, high plane (Fig. 219).

Pes Adductus. The position of the shafts of the metatarsal bones belies this foot type. The differentiation must be made between congenital foot type and compensated weak-foot. In the foot of immature bone development this is difficult unless the talo-calcaneal relationship is carefully appraised In adductus the two bones are closely bound (Fig. 220).

Metatarsal Disorder. As has been previously noted, the secondary centers of ossification for the metatarsal heads and the base of the proximal phalanges are late in maturation; consequently, little is to be gleaned until sufficient development has been completed. Metatarsal length patterns are identified in the child and hypertrophy and atrophy may be discerned. This indicates that Wolff's law may be at work very early in the formation of altered shapes.

"Aseptic necrosis" of the second metatarsal head has been described by Frieberg as an infraction. This clinical entity is an osteochondrosis similar in nature to Koehler's Disease of the navicular. Minimal traumatic stress reactions

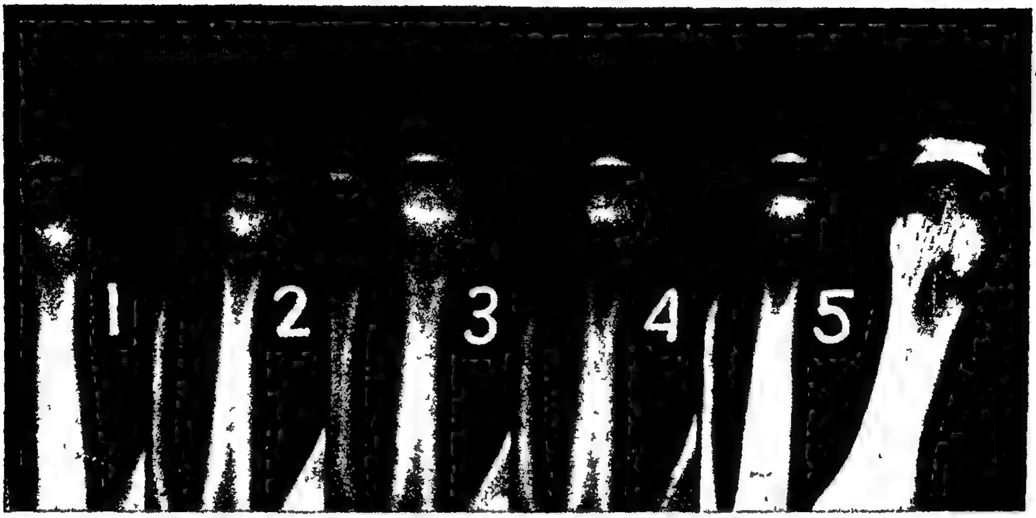

FIG. 221. OSTEOCHONDROSIS OF SECOND METATARSAL HEAD. (1) First evidence: flattened head, increased joint space. (2) Two months later: fibrocystic degeneration of head. (3) Two months later: reparative mineralization. (4) Three months later: more dense mineralization, normal epiphysis eliminated, maturity accelerated. (5) Six months later: repair established, deformity at a minimum because of adequate protective care.

imposed on the physiological development of the distal epiphysis seem to be the causative factor, with the possibility of acute trauma in some cases. The problem is in no wise restricted to the second metatarsal head. All lesser metatarsal heads have been involved according to case studies of the author. A close follow-up series of radiographs has provided an interesting study of the progress of the problem. The outstanding feature seems to be premature maturation and consequent deformation of the metatarsal head because of the excessive mineralization of the epiphysis during the accelerated growth. The stages are illustrated (Fig 221).

Impingement factors may be present in the child's foot, and the various malalignments in varus and valgus slant Subluxation is not as common in the child's foot as in the adult foot because the child does not wear high-heeled shoes which favor the contraction of extensor tendons of the toes with subsequent metatarso-phalangeal luxations

Pathology of this region is limited since the arthritis syndromes do not involve the child's foot as frequently as the adult's. The entire gamut of joint pathology may attack the metatarso-phalangeal joints

Orthodigital Problems. The diverse conditions classified as orthodigital problems are in many instances allied to congenital etiology. Hallux valgus may be frequently identified on the radiograph of the child, and the atavistic shape of the medial cuneiform or first metatarsal base recognized at an early age. Likewise, hallux varus may be visualized as a natural position of the hallux in the new-born child Overlapping and underlapping toes should be radiographed in infancy so that due importance may be placed on the problem and a record produced that will be useful in later comparison following rehabilitative treatment. Minimi digiti quinti varus is a congenital malformation. Hammer toes of congenital origin will be identified early in the radiograph of a child.

Factors Producing Excrescences. Toes that are distorted from normal alignment may be identified in early foot radiographs. The fully matured phalanges do not materialize until the child reaches majority; consequently, irregular ossification as a basis for the development of helomata may not be identified on the radiograph.

Significant Variations. The early ossific nuclei for the os trigonum is a potent lesson in differentiating this supernumerary bone from fracture of the tip of the posterior tubercle of the talus. It is rounded in contour whereas fracture lines are serrated and the fragments fit together.

All of the significant variations develop from specific ossification centers and are a part of the maturing foot skeleton. Defects of development like aplasia should be followed by a series of radiographs because of the chance that additional ossification nuclei may put in a late appearance.

Clinical Consideration

The application of the impressions gleaned from radiographs of the child's foot have wide clinical significance. Various phases have been discussed throughout the text of this chapter.

The surface has only been scratched in research concerning skeletal maturation and many clinical problems. More basic data need to be accumulated.

It is predicted that rays will be attuned to the density of cartilage so that radiographs of the pre-mineralized bones may be as carefully evaluated as the mature adult foot.

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Chapter XII

Roentgen Report of the Foot Case

An orderly analysis should be recorded of every foot case that is examined roentgenographically. The extensive descriptions of the various patho-anatomical features which typify foot types and various clinical entities should be reduced to concise and informative impressions and conclusions.

Although it would be perfectly proper to report patho-anatomical foot cases (Fig. 222) in the conventional descriptive manner commonly used in reporting pathology *per se*, under these circumstances it would be very easy for the examiner to become involved in a plethora of anatomical description that would be unwieldy. It is therefore expedient to simplify reporting of this type by means of a chart designed for this purpose. When a syndrome such as mid-tarsal fault is present, the examiner need only check this finding instead of undertaking a complete anatomical description of the syndrome (Figs. 223, 224)

No matter what method is used, a comprehensive written record should be added to the clinical records of the case for reference. Merely summarizing roentgen features or impressions on the filing envelope is poor practice when substituted for a substantive report. When the doctor acts as a consultant, it is absolutely necessary that a written report be prepared for the referring doctor.

This author has devised a report form that embodies four distinct features: Graphic Analysis; Report of Patho-anatomical Features; Roentgen Report; Case Classification and Roentgen Diagnosis. These features will be described and their usefulness explained

GRAPHIC ANALYSIS

This section of the form consists of x-ray tracings of lateral and dorso-plantar radiographs of normal feet. Upon examining the radiographs of a case in question, the doctor may indicate upon the tracings any changes of alignment that have transpired by drawing arrows to show the direction of the alterations. Variations in the shapes of the bones may be drawn. Areas under pathologic suspicion may be circled. Fracture lines may be indicated.

Through this medium a graphic report which is easy to visualize is available. It eliminates the temptation to mark radiographs which can be defacing.

This report serves as the initial guide from which the practitioner may work in filling out the remainder of the report.

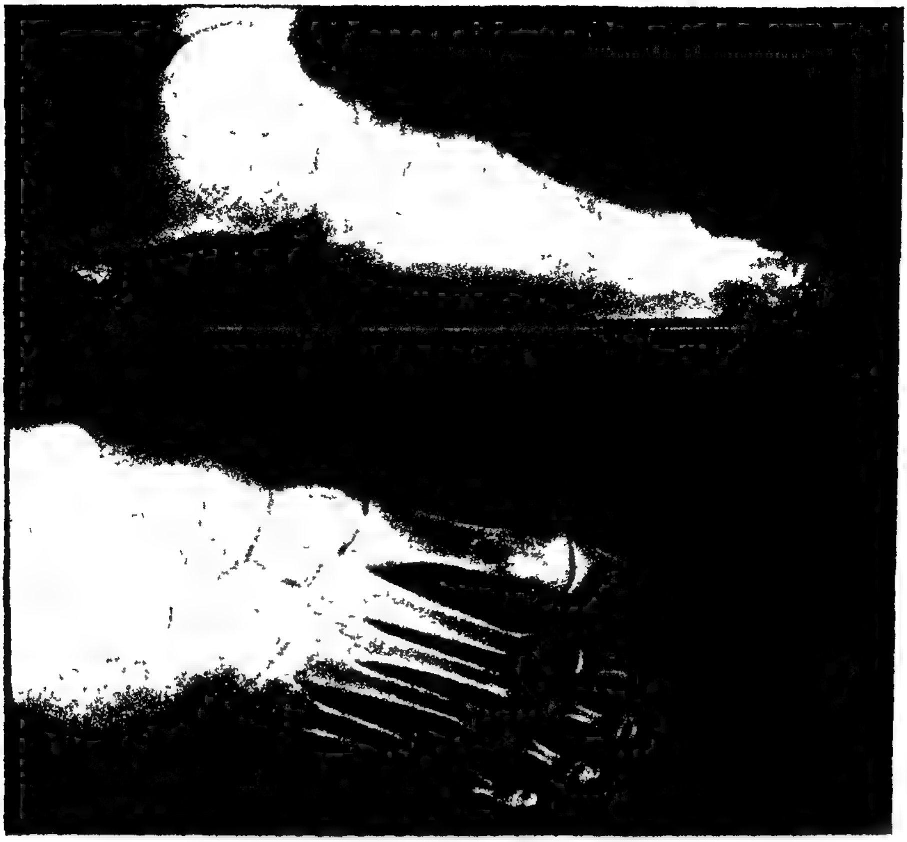

FIG 222. RADIOGRAPH OF PATHO-ANATOMICAL CASE REPORTED.

CASE CLASSIFICATION AND ROENTGEN DIAGNOSIS

Pathology of bone Minimal traumatic arthritis.

Fracture

Chiropodical

Orthodigital Contracted toes.

Pathomechanical Severe Midtarsal Fault, Severe Navicular-cuneiform Fault.

Arch height Medium.

ROENTGEN REPORT

The calcaneus is everted and lowered in pitch.

The talus has rotated medially and has pivoted forward and downward.

The navicular-cuneiform joint is depressed.

The inner arch segment is rotated medially with displacement of the medial cuneiform, first metatarsal and sesamoids.

Flattening of the transverse arch creates a rotated third metatarsal that directs the head into juxtaposition with the second metatarsal and the second and third toes deviate apart.

Hypertrophy of the shaft of the second metatarsal is a sequel of Morton's syndrome.

The toes are contracted.

Minimal traumatic arthritis is evident in eburnation of numerous articulations.

FIG. 223. CASE CLASSIFICATION—ROENTGEN DIAGNOSIS—ROENTGEN REPORT.

GUIDE TO ROENTGEN INTERPRETATION OF PATHOMECHANICAL FEATURES

(Degree of condition reported for
Left foot Right foot)

Acquired Long arch depression

_______ Sev. a. Mid-tarsal fault
_______ Sev. b. Navicular-cuneiform fault
_______ _______ c. Calcaneo-cuboid fault
_______ _______ d Atypical - see report

Compression and Alignment Changes

_______ X (See report)

Congenital long arch depression

_______ _______ a. Planligrade os calcis
_______ _______ b. Rotation of talus
_______ _______ c. Abduction of forefoot
_______ _______ d Atypical - see report

Cong. long arch depression plus changes

_______ _______ a Adduction of forefoot
_______ _______ b. Mid tarsal fault
_______ _______ c Navicular-cuneiform fault
_______ _______ d Calcaneo-cuboid fault

Pes Cavus

_______ _______ a Congenital
_______ _______ b Acquired
_______ _______ c Atypical - see report

Pes Adductus

_______ _______ a. Forefoot adduction
_______ _______ b. Hindfoot inversion
_______ _______ c. Atypical - see report

Mortons Syndrome

_______ X

Metatarsal Lesions

_______ X a. Discrepancies in length
_______ X b Impingement factors
_______ _______ c Club shape abnormalities
_______ _______ d Varus and valgus slant
_______ _______ e M P joint subluxations

Orthodigital lesions

_______ Mild a Hallux valgus
_______ _______ b Hallux varus
_______ _______ c. Hallux flexus
_______ _______ d Hallux limitus
_______ _______ e Overlapping toes
_______ _______ f. Underlapping toes
_______ _______ g Hammer toes
_______ X h Sesamoid lesions

Significant Anomalies

_______ _______ a. Tibiale externum
_______ _______ b. Intermetatarsum
_______ _______ c. Os Fibulare
_______ _______ d Os Peroneum
_______ _______ e Os Trigonum
_______ _______ f. Haglund's deformity
_______ _______ g Other anomalies

Key to degree of condition -
Mild - Moderate - Severe - Extreme

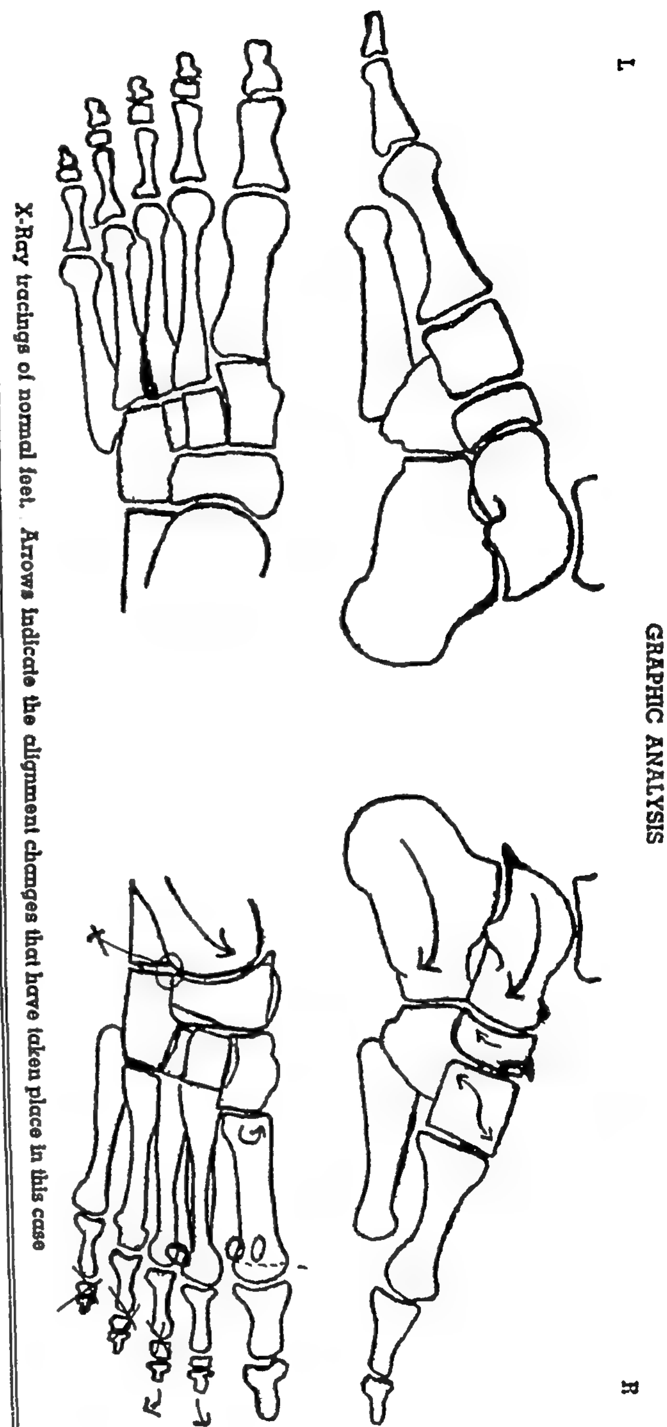

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FIG 224 REPORT OF PATHO-MECHANICAL FEATURES—GRAPHIC ANALYSIS

REPORT OF PATHO-ANATOMICAL FEATURES

A rather complete list of the patho-anatomical conditions that are found in foot cases is offered as a guide so that the practitioner may easily check any case in question with complete system. Since a written description of patho-mechanical changes would be tedious and entirely too lengthy, each major patho-mechanical condition serves as a topic heading under which the various significant syndromes, features, or other data may be listed. Oposite the sub-headings there is a space allowed so that the degree of the condition may be reported for each foot. The key to the degree of the condition consists of the following classification: mild, moderate, severe, and extreme.

The complete guide consisting of the clinical listing follows:

Acquired Longitudinal Arch Depression

(a) Mid-tarsal fault
(b) Navicular-cuneiform fault
(c) Calcaneal-cuboid fault
(d) Atypical (see report)

Compression and Alignment Changes

(a) (See report)

Congenital Long Arch Depression

(a) Plantigrade calcaneus
(b) Rotation of talus
(c) Adduction of forefoot
(d) Atypical (see report)

Congenital Long Arch Depression Plus Changes

(a) Adduction of forefoot
(b) Mid-tarsal fault
(c) Navicular-cuneiform fault
(d) Calcaneo-cuboid fault

Pes Cavus

(a) Congenital
(b) Acquired
(c) Atypical (see report)

Pes Adductus

(a) Congenital
(b) Acquired
(c) Atypical (see report)

Morton's Syndrome

(a) (See report)

Metatarsal Lesions

(a) Discrepancies in length
(b) Impingement factors
(c) Club-shape abnormalities
(d) Varus and valgus slant
(e) Metatarso-phalangeal joint subluxations

Orthodigital Lesions

(a) Hallux valgus
(b) Hallux varus
(c) Hallux flexus
(d) Hallux limitus
(e) Overlapping toes
(f) Underlapping toes
(g) Hammer toes
(h) Sesamoid lesions

Significant Anomalies

(a) Tibiale externum
(b) Inter-metatarsum
(c) Os fibulare
(d) Os peroneum
(e) Os trigonum
(f) Haglund's deformity
(g) Other anomalies

ROENTGEN REPORT

The space devoted to roentgen report is provided for a written description of pathological processes with a complete record of the findings. Any other specific data that are not covered by the patho-mechanical report may be recorded in this space, including atypical conditions that require detailed explanation.

CASE CLASSIFICATION AND ROENTGEN DIAGNOSIS

So that the doctor may see at a glance the type of case which confronts him, a case classification is offered that is followed in reporting the roentgen impression, conclusion, or diagnosis

The classification is not a strict one for the same case may overlap several classifications Nevertheless, it is very expedient in actual practice and is used in the cross-index of the condition file.

The classifications consist of the following:

(1) Pathology of bone
(2) Fracture
(3) Excrescence
(4) Orthodigital
(5) Patho-mechanical
(6) Arch height

The designation, arch height, is reported jointly with any condition affecting the longitudinal arch It is an appraisal of the original arch height so that the present condition may be compared.

OTHER FEATURES OF THE FORM

The items of Case Requisition, Technical Factors, and Case History, are also a part of the form. These topics will be fully discussed in the next chapter.

CORRELATING ROENTGEN REPORT WITH CLINICAL FINDINGS

Throughout the chapters of this book, clinical considerations have been developed about every phase of interpretation. The doctor must use this knowledge and apply it to each case. The roentgen report clinches the diagnosis, offers the degree of fault so that prognosis may be appraised, and by the very comprehensive evaluation of the patho-anatomy opens the scheme for treatment.

SECTION

TWO

OFFICE PRACTICE

Chapter XIII

Roentgenology in the Foot Practice

No matter how large or how small the volume of radiographic work performed in an office, a systematic scheme of administering the various work areas should be established. Responsibility for management and maintenance of equipment and supplies should be fixed; special duties for secretary and technician, including supervision of records and filing, should be defined; the staff should be thoroughly familiar with the types of roentgen examination; and management of patients should follow an established routine. The entire staff should be informed of the risks related to radiant energy and protective measures discussed in detail. These matters will be further explained later on in this chapter.

DUTIES OF PERSONNEL

The small office staff usually consists of the doctor and a secretary-assistant. The doctor assumes the responsibility for performing the radiographs and dictating the reports. The assistant has a multitude of duties. Among these are maintenance of the processing room in an orderly fashion and this includes the following: filing of exposure holders, printing of identification on films, processing of radiographs, replenishment of processing solutions, ordering of film, solutions, and sundries, initial patient management, recording of preliminary data, transcription of the doctor's reports, filing and cross-indexing of all radiographic records, and rendering assistance to the patient and the doctor during the roentgen examination.

In the large office, more auxiliary personnel are available and the work is divided. The secretary-receptionist initiates patient management by recording the preliminary data. The nurse-assistant prepares the patient for examination and assists with all patient handling. The doctor conducts the preliminary examination and requisitions the radiographic views needed. The doctor also dictates the roentgen report which the secretary transcribes She also files the films and she records the case in the cross-index system. The technician performs the radiography and processes the films. He is also responsible for darkroom maintenance, including the care of equipment, the replenishing of solutions, and the requisitioning of orders of the current inventory of supplies.

RECORDS

The importance of a thorough method of recording data pertaining to the roentgen examination cannot be emphasized too strongly. The roentgen diagnosis is the object of any radiographic examination and should be explicitly recorded under every circumstance. The roentgen report gives a finality to clinical diagnosis. It is the responsibility of the doctor to dictate the report in good order. Another chapter details a complete system for reporting roentgen findings in foot cases. In the usual practice, the report of the case is developed for the sole use of the doctor. There is no need to duplicate data that have already been recorded on a clinical chart on the report form. In formulating a final diagnosis of the case the doctor will naturally refer to the clinical and laboratory records as he considers the radiographic findings.

Every roentgen examination can be considered, *primæ facie,* evidence of a medico-legal nature. In order to satisfy a court of law, certain basic information concerning the identity of the film is needed. Consequently, attention must be given to the correct spelling of the patient's name. In addition, the exact date and the doctor's name and location should be recorded on the identification requisition. A master log serial number may be affixed in lieu of the patient's name if this system is used by the office

Details concerning the technical factors used in the examination are listed as a matter of reference.

Basic Report Form Data (Fig. 225). Regardless of whether the case is a private one or referred, it is necessary to correlate the following: the patient, the radiographic technique, the clinical history and the roentgen report.

Name. The patient's last name, followed by his given name and middle initial are recorded.

X-Ray Number. The serial number assigned to the case from the master log of radiographs is the connecting link between the master log, the radiograph, the patient, the x-ray report, and the condition file of the cross-index system. Corrective department and/or chiropody department numbers may be listed for correlation

Address. In the event that contact need be established with the patient to notify him of a serious condition or to arrange for re-examination, it is absolutely necessary to record the address of the patient.

Referred By In cases referred by doctors outside the practice, the name and address should be listed so that the transcript of the report may be promptly sent to the correct address

Date of Examination. This is primarily for medical reference, although it may possibly be of use for a legal record

Region Examined. Before executing an examination, the doctor must determine precisely the region or area to be examined. This is recorded upon the x-ray requisition

Radiographic Views and Time Factors. The technician may record the views that were used in composing the examination. When time is used as a variable factor, it may be recorded to expedite the radiography.

Technical Features Other radiographic factors, including peak kilovoltage, milliamperage, distance from anode to film, and type of film, are recorded so that these details may be available for reference In the case of a radiograph that

X Ray Number ______ Corr. No. ______ Chir. No. ______

Name ______ Date of Exam. ______

Address ______ Region examined ______

Referred by ______ Radiographic views & Time Factors ______

Address ______

XVP ______ Ma. ______ Dist ______ Type of film ______ Posture ______ No. film ______

BRIEF HISTORY OF CASE WITH PHYSICAL FINDINGS

Chief Complaint ______

Onset ______ Duration ______

Nature of trauma ______ P. M. H. ______

Age ______ Weight ______ Previous x ray examinations ______

Physical Appearance ______

Temp. ______ Fluc. ______ Blood findings ______ Urine ______

FIG. 225. BASIC REPORT CHART.

lacks the qualities desired, reference to the radiographic factors used would provide a means of correcting the fault. The data may also be used to duplicate a technically perfect film if needed.

Posture. The attitude of the patient, be it static, recumbent, or semi-recumbent, is recorded so that the radiograph may be better appraised.

Number of Films. This enables an office check to be sure that all films used in the examination are available. It is also used in accounting for the stock of films on hand and the number which have been run through the processing solution.

Pertinent Clinical History. Although radiographic diagnosis is basically an objective report of the findings visualized on the radiograph, the impression carries through to the clinical problem. Certain clinical information about a case is helpful in correlating the roentgen findings. A list of essential information, some of which is frequently necessary in filing reports for various types of insurance claims, is given here.

Chief Complaint The nature of the case is usually disclosed by the patient's description of his chief complaint. The mode of onset and the duration provide key information.

Nature of Trauma. In traumatic cases, the original date of the injury should be given so that the examiner can correlate his x-ray findings with the duration of the injury As a matter of record, the circumstances of the accident should be stated in the patient's own words. This helps in assessing the radiograph, especially in such a case as an avulsion in the instance of a twisted foot, or an impaction in the instance of jumping from a height, etc

Previous Medical History. In cases of a pathological nature, it is most helpful to know of any systemic diseases that are likely to be related to the area under examination

Age The patient's age will give the doctor a clue to the bone density he may normally expect of the radiograph. For example, age and ossification centers are intimately related in the radiograph of young subjects. In older subjects, senile atrophy, which must be differentiated from other active forms of atrophy, may be established.

Weight. This sometimes serves as a guide in deciding exposure factors

Previous Roentgen Examinations. These are noted as a safety precaution. Roentgen irradiation has a cumulative effect upon tissue; consequently, tissue destruction can take place when safety limits are exceeded. If previous examinations have been made, the total number of milliampere-seconds of exposure that have been given must be computed and then compared with an accepted chart of safety factors. In order to safeguard the patient from excessive radiation, he should be questioned to find out if roentgen or radium treatments have been administered.

Physical Appearance. The characteristic foot appearance of various pathoanatomical disorders, such as abduction, eversion, etc., should be recorded for reference. Limitations in the normal range of foot motions may be included under this heading. This may help in the evaluation of bony blocks to motion.

Temperature and Fluctuation. Two of the cardinal symptoms of infection with abscess formation are elevation of temperature and fluctuation of the tissue under palpation. When these symptoms are present, notation to this effect should be made.

Laboratory Findings. Obviously, the laboratory report concerning blood examination should be correlated with the roentgen findings, if possible. This applies to biopsy and other laboratory findings.

FILING SYSTEM

Although the primary function of the roentgen department of any practice is to supply diagnostic criteria, it is a well established fact that a good system of cross-indexing will supply the doctor with a veritable library of roentgenographic material (the radiographs, the case histories, and the radiographic reports) which is an invaluable source of reference. Should the doctor wish to study a particular category of conditions, it is a simple matter to refer to the index of conditions and withdraw all such cases.

The elements of the filing system will be described and their functions explained.

Master Log of Cases. A log book of the cases radiographed is kept, with the following entries: x-ray number, date of the examination, name and address of the patient, name and address of the doctor in case of referral, and coding for fee. This log provides a serial number for each new x-ray case The chronological record may be referred to as an aid in locating a radiograph when the approximate date of examination is the only known data. The log book is not often used in study, reference, or research. Its chief function is to keep an accurate record of transactions for the roentgen department.

Filing Roentgen Report Forms. The roentgen report form, which has been described and explained, is filed in the x-ray film filing envelope which has the x-ray log number and the patient's name lettered on the outside. These envelopes may be filed alphabetically.

Active Case Radiograph File Cases under active treatment may be kept in an open case for convenient access. This simplifies the daily routine of obtaining radiographs of current cases from the file.

Inactive Case Radiograph File. Cases that have reached an inactive status in the practice are transferred to a large x-ray filing cabinet and there they become a part of the x-ray library.

Referred Case Radiograph File. When the radiographs of referred cases are kept on file, a separate filing case should be provided.

Indexes

Index of Roentgen Reports. An index of roentgen reports is kept on cards of suitable size and arranged in alphabetical order according to the names of the patients. It is this mode of filing which keys in with the radiographic file and the index of conditions. A transcript of the case classification and the roentgen report is written on the record card, as is the x-ray number.

Index of Conditions. A full-view type of cabinet system is used to display the index of conditions. The conditions are classified under the five case classifications and represent every type of case that has been radiographed by the doctor. On each card representing a condition, a list of every case radiographed is entered and indexed according to the patient's name and x-ray number.

How to Use the Cross-index System. The chief use of the cross-index system is for the purpose of making a study of one or more conditions. Hence the doctor first refers to the index of conditions to find the card that contains the list of cases of that condition that have been radiographed. This card gives the name and x-ray number of the cases. The doctor then consults the radiographic file for the roentgen report and the radiographs for visualization.

If the doctor is interested only in the written characteristics of the cases, the index of conditions will supply a list of names that will key in with the index of roentgen reports, thus providing the information needed for his study.

TYPES OF ROENTGEN EXAMINATION

Foot practice utilizes several types of roentgen examination. They may be logically divided into the following categories: emergency roentgen examination, pre-operative roentgen examination, foot orthopedic roentgen examination, and excrescence exploratory roentgen examination. In discussing the various types of examinations, phases of patient management and psychology will be considered, especially as they relate to the mode of directing the need for examination and the manner in which the results of it are presented to the patient

The intimate contact between doctor and patient found in private practice calls for a manner of handling the examination results that differs from that used in a doctor-roentgenologist referral report A few patients may be satisfied with the statement of the roentgen findings, but they are definitely in the minority. Most patients expect to see the radiographs that have been made Presentation of findings and actual display of the radiographs for the patient must be handled with tact and authority. The doctor must bear in mind the personality traits of the patient involved and must decide upon his approach to each case accordingly.

Sometimes a patient requests possession of the radiographs after the case has been presented. The doctor should explain that for the protection of the patient the radiographs must be retained in his files for future reference In cases involving litigation, the doctor is frequently requested to present radiographs for evidence. Should the doctor allow the patient to possess the radiographs, he may find at the time of the trial that the patient has lost them.

Aside from the legal aspects, there are many good reasons for the doctor to

keep the radiographs on file. The patient may wish to take the radiographs to another doctor to compare diagnoses. Or perhaps he may wish to use the radiographs as a curiosity. Retention of the radiographs by the doctor precludes any mishandling of a very important clinical report. In most cases, the doctor needs the radiographs for constant reference during the course of treatment in order to check the progress of the case. No better reason could be offered to the patient for the doctor to keep the radiographs instantly available. However, if the patient should become unreasonable in his insistence, the doctor must be firm in stating that radiographs have been legally declared a part of the doctor's record of the case If necessary, a transcript of the findings may be made and given to the patient. Of course, the doctor will assure the patient that he will transmit the radiographs directly to any consultant chosen by the patient or the doctor.

Emergency Roentgen Examination. An emergency roentgen examination is one that is made to determine the cause of acute symptoms. Usually the case is traumatic, such as a fracture or a sprain, although it may be of a pathological nature (Figs 226, 227).

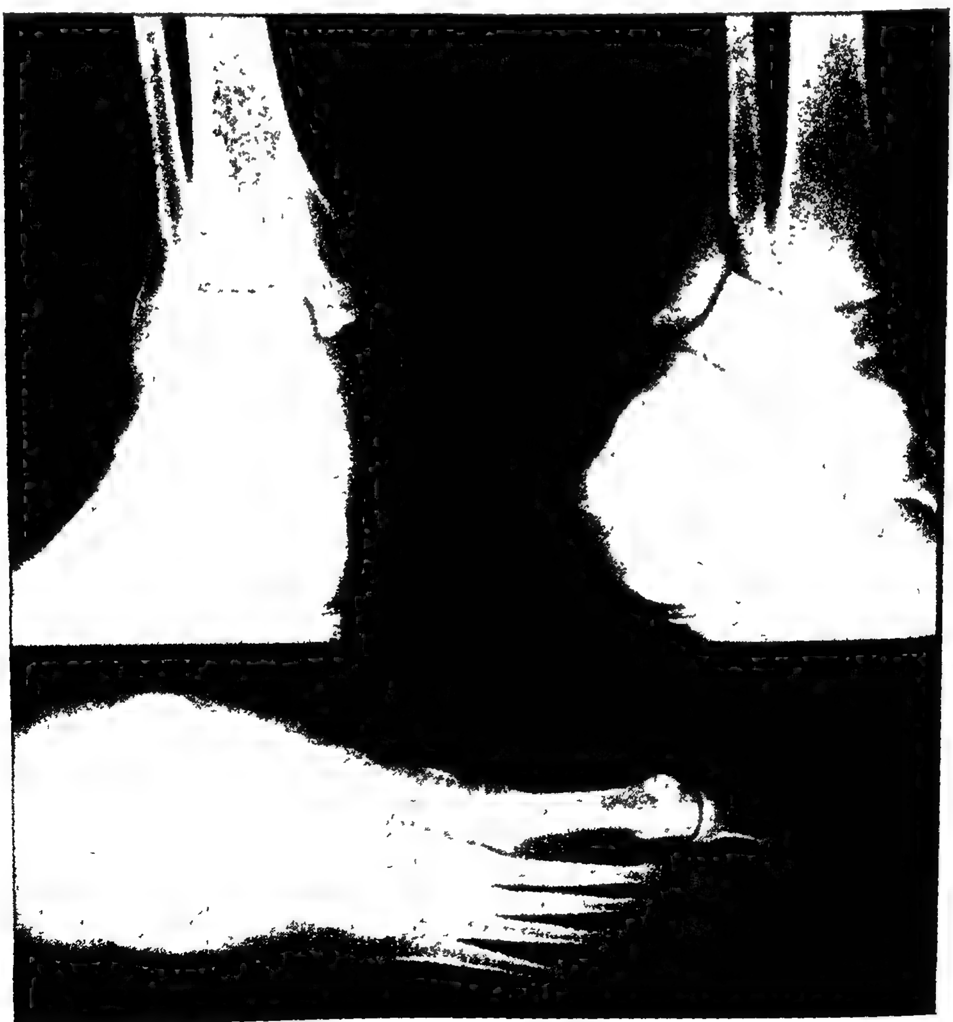

FIG 226 EMERGENCY ROENTGEN EXAMINATION—FRACTURE.

No special direction is necessary in requesting an x-ray examination, since the patient is in pain and wants to know why as soon as possible. Following preliminary clinical examination the doctor performs the roentgen study.

There is no special need to display radiographs of a fracture to a patient unless requested to do so. The patient usually receives the information by either over-estimating or under-estimating the seriousness of the condition. The manner of presentation of the radiographs should emphasize the case in the light that meets the situation at hand.

In cases of bone pathology, the patient would be incapable of understanding the roentgen evidence. Thus it is unnecessary to display the radiograph.

Pre-operative Roentgen Examination. A pre-operative roentgen examination is recorded on x-ray film prior to any foot surgery. Its purpose is to indicate the operative work needed and to disclose any pathology that may complicate the case (Fig. 228).

Operative surgery is usually the result of a clinical evaluation of a critical lesion; consequently, the request for an x-ray examination is a simple and direct one In some cases of elective surgery it is well to explain that roentgen examination reveals the complete bone shape so that every phase of the surgery may be planned in advance. This is particularly true in hallux valgus problems.

Judgment should be exercised in deciding whether or not to discuss a surgical procedure with the patient. If it seems warranted, the radiograph is a visual portrayal of the bony elements and is helpful in such an explanation. Generally, there is no need to go into detail over operative procedures with the patient

FIG 227 EMERGENCY ROENTGEN EXAMINATION—PATHOLOGY Osteochondroma Pre- and post-operative radiographs. (Courtesy of Dr. Earl Zatz)

FIG. 228 PRE-OPERATIVE ROENTGEN EXAMINATION—HELOMA DURUM, FIFTH TOE. Pre- and post-operative diographs (immediate and thirty months later). (Courtesy of Dr Lester A. Walsh)

Foot Orthopedic Roentgen Examination. The entire gamut of patho-anatomical problems that the foot is most likely to sustain are best completely evaluated by roentgen study of the bony elements (Fig 229). However, a comprehensive clinical examination of each case should always precede the orthopedic x-ray examination. When sufficient evidence sustains the need for x-ray examination, the patient should be told that an x-ray study of his feet will be made in such a manner that the bones will be visualized as he is standing, in order that the full import of the condition, as it exists when symptomatic, will be shown. The films should be prepared immediately, and the examination carried through with dispatch.

It is advisable to explain the radiographic findings to the patient in practically every foot orthopedic examination. The importance of the consultation should be emphasized by an atmosphere of thoroughness All clinical records and data should be at hand, and the radiographs of both feet should be illuminated side-by-side for easy comparison. The doctor should draw attention to a few salient features of the radiograph that relate to the clinical symptoms such as, for example, a mid-tarsal fault which is a site of pain on digital pressure The degree of disorder should be explained and the plan for rehabilitation discussed. Careful attention to this consultation will prepare the patient for the tedious and sometimes lengthy treatment program that is in store for him. It is often helpful to have in readiness a radiograph of a normal foot to compare with the disordered foot.

The presentation should not be overdrawn, since it seems that the patient can always see more wrong in the radiographs than the doctor can. Furthermore, too long a discussion will confuse the patient. Make several important points

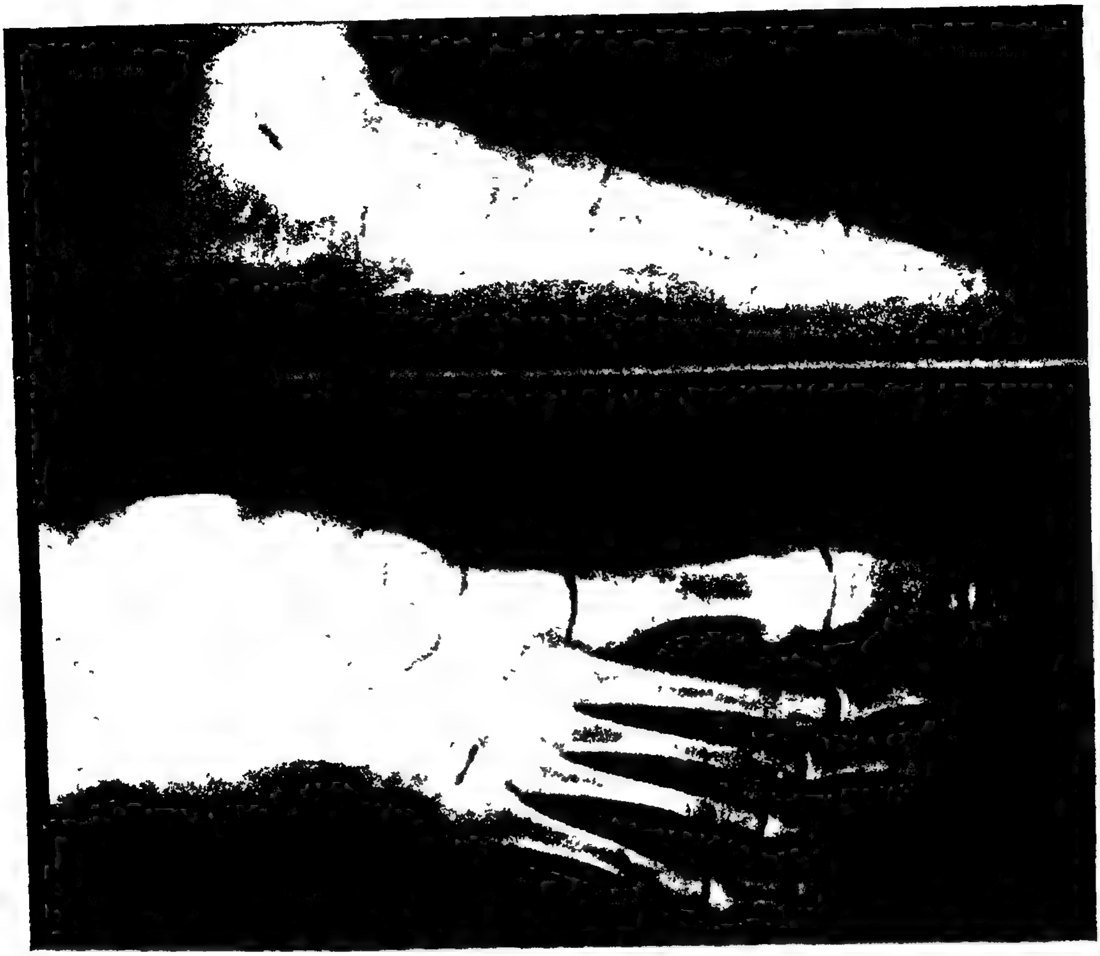

FIG. 229. FOOT ORTHOPEDIC EXAMINATION.

clear, state the prognosis, explain the treatment plan, and then tactfully conclude the interview.

Excrescence Exploratory Roentgen Examination. This type of examination is an innovation As its name implies, the examination explores the etiology of common excrescence lesions by x-ray (Fig. 230). In utilizing this type of examination in practice, a routine manner should be used. The radiograph consists of two dorso-plantar exposures on one 10 in. x 12 in x-ray paper or film. The first one is a view of the toes in the shoes (Fig. 231) and the second is of the toes unshod but with the excrescences marked with zinc oxide ointment (Fig. 232) After it is seen that the patient has excrescences, he is transferred to the x-ray room and told that an exploratory x-ray examination is to be made, first with the shoes on and then without the shoes, as a part of the diagnosis and record of his case The examination is then carried through as expeditiously as possible.

At a subsequent visit, the exploratory radiograph, depicting the excrescences as areas of increased density where they are marked by the zinc oxide, is explained to the patient Instances of exostosis or roughened bone that are responsible for the excrescence are discussed and the possibility that surgery may cure the condition is pointed out. Orthodigital toe-straightening procedures are

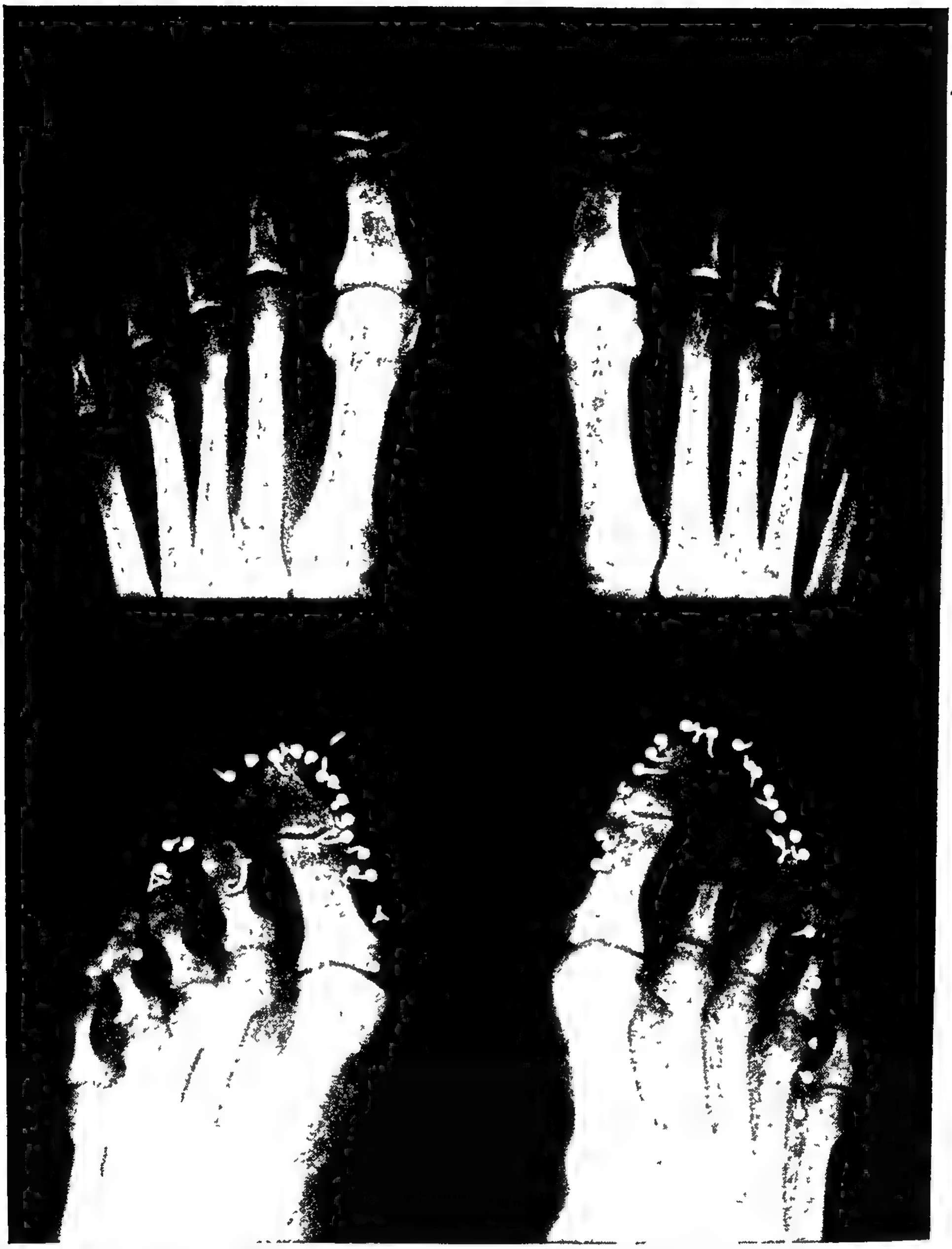

FIG 230 EXCRESCENCE EXPLORATORY ROENTGEN EXAMINATION Radiograph on 10 in x 12 in size. Toes in shoes on half Toes unshod but excrescences marked with zinc oxide on half.

discussed in cases of mal-posed toes The factor of a shoe shape that is incompatible with the toes is explained to the patient and the proper shoe prescribed.

Of course, the type of roentgen examination used in excrescence exploration should be in addition to any orthopedic roentgen examination if the case presents problems in both categories

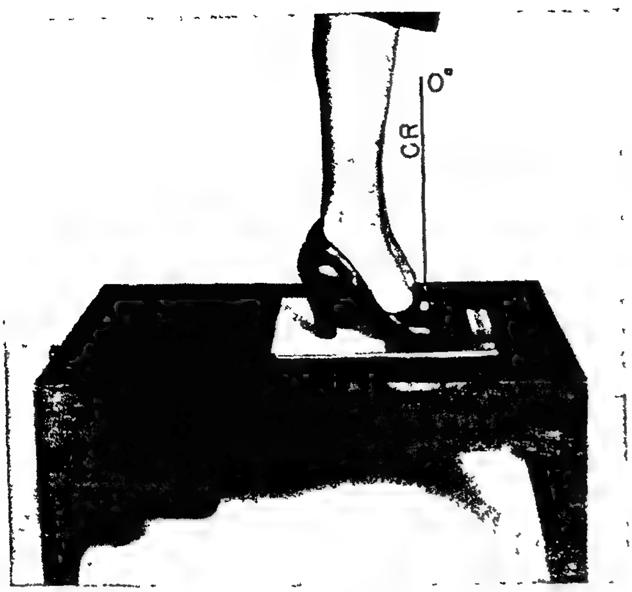

Fig. 231. Excrescence Exploratory Roentgen Examination. First exposure with toes of shoes over film. Other half protected with lead blocker.

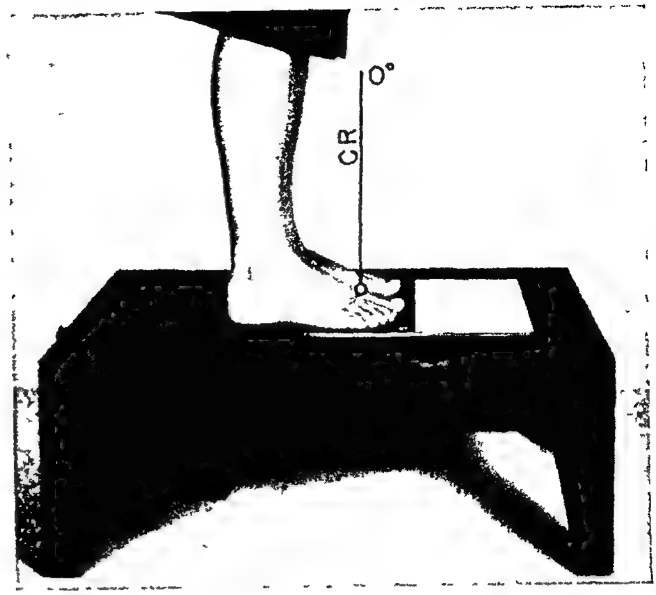

Fig 232 Excrescence Exploratory Roentgen Examination. Second exposure toes unshod but marked with zinc oxide Previous exposure protected with lead blocker. Central ray directed midway between feet, or individual exposures to midline of foot if quarter film blocker is used.

PATIENT MANAGEMENT

From the time the patient is admitted to the foot practice until he is dismissed, there is the constant problem of management of his needs. The services rendered to the patient by the roentgen department of the practice should be performed efficiently. Patients enter the practice for various reasons, and those requiring emergency x-ray examination require special management. Likewise, patients that are referred by another doctor for x-ray examination should have special consideration. Other patients are a routine part of the practice, and their management is integrated with normal procedures.

Emergency Roentgen Examinations. When the receptionist greets an emergency patient for the first time in the waiting room, she should quickly size up the situation and concentrate on making the patient as comfortable as possible. The patient should be quickly transferred to the x-ray department in a mobile chair. Data for the basic report form and pertinent case history should be recorded with dispatch. Meanwhile, the nurse-assistant should remove the shoe, stocking, and dressings from the affected area and usually from the other foot as well because the doctor may decide to x-ray it for comparison. The doctor is given the report chart, examines the part under suspicion, and decides upon the roentgen study to perform. The x-ray technician executes the roentgen examination with every possible aid to make the patient as comfortable as possible The doctor then applies suitable dressings, and the patient is dismissed. Transportation and comfortable handling of the patient from office to car is supervised.

The Referred Patient. The occasional patient referred by a colleague should receive systematic service Frequently, the case is of an emergency nature so that the same procedure as above is followed. The foot orthopedic roentgen ex-

amination should follow a standard admission technique by the secretary-receptionist in which she conducts a preliminary interview with the patient to obtain the basic report form data and the pertinent case history. The patient is allowed to wait in an examination room until the doctor has studied the information about the case, examined the part, and instructed the technician concerning the proper roentgen study. The patient may then be transferred to the x-ray room. Paper slippers are handy, but caution should be used when floors are waxed. Following the examination the patient is told to contact his doctor for an appointment concerning the x-ray report.

Routine Patients. The patient requiring foot orthopedic roentgen examination is usually transferred directly from his clinical examination to the roentgen examining room. All of the basic report data and clinical history have been recorded as a part of the examination and need not be transferred to the x-ray report form in detail. Only those data dealing with identification and radiographic factors should be recorded.

Preparation for the Roentgen Examination. All dressings and adhesive tape residue should be removed Be sure that all traces of adherent, such as Griswold's Salve and Mason's Cedar Plaster, are removed because they are radio-opaque and would be visualized as a smudgy area of increased density on the film.

Prior to admitting the patient, the equipment is set in complete readiness for the first exposure. There should be no fumbling with equipment after the patient enters the x-ray room.

Conducting the Roentgen Examination. When everything is in readiness, the patient is admitted to the x-ray department and placed in the proper radiographic position without any delay The first exposure is then promptly instituted.

Usually the patient cannot realize that an exposure has been made in such a short time, but this effect is a desirable one because the patient then feels perfectly at ease for whatever subsequent exposures are necessary The rest of the exposures should be done as quickly as thoroughness will permit. Lagging procedure is likely to make the patient ill at ease It also gives him time to ask those questions about equipment, etc , which are distracting and can waste time.

Manipulation of the equipment should be thoroughly mastered so that the proper planes of exposure may be executed with facility. Care should be taken not to appear awkward The electrical features should be checked during exposures. No mention of high voltage should be made.

After each film has been exposed, the film is placed in the rayproof storage bin, and the next loaded film-holder is immediately made available for the next exposure

Careful planning and teamwork can reduce the time element to a minimum; thus, greatly simplifying management of the patient.

RADIATION RISKS

The matter of permissible radiation exposure is under constant study and revision due to the increased use of radioactive substances. The National Bureau of Standards publishes revised Handbooks which contain all of the details

concerning risk and protection. These are available through the U. S. Government Printing Office, Washington. It is urged that every doctor using any form of radiation keep well informed on every phase of this highly potent form of energy.

Any of the body tissues may be damaged by over-exposure to x-rays, but the skin, the blood, the lymph glands, and the genital organs are most sensitive. The patient is exposed to the primary beam only on the occasion of the radiographic examination, but he may develop reactions from these exposures if they are sufficiently intense. The x-ray operator, on the other hand, is continually exposed to small doses of scattered rays and at times to the primary rays. Unless such exposure is kept at a minimum the cumulative effect is apt to cause damage to the body.

The operator must bear in mind at all times that his tissues are like a sponge in their accumulation of radiation and that the tissues act as a store-house until rested sufficiently to dissipate the dosage. Quimby points out that the body is capable of handling small amounts of radiation without any harmful effects up to a safety limit of 0.1 r per day. This quota refers to general body radiation, not to local exposure.

Over-exposure in terms of radiation injury is described by Stone as follows: In *acute local over-exposure*, the skin becomes red and may blister. The lesion is slow to heal. In *repeated or chronic local over-exposure*, there is no erythema, but the skin becomes tight and wrinkles and ridges disappear. Later on crusts or warts will form. In a few people, these crusts and warts will turn into skin cancer. When there is local irritation of hair-bearing areas, the hair falls out before any skin reactions appear; if the dose is light the hair will come in again within a few weeks or months. The effect on the testicles and ovaries is sterility rather than impotence. When there is radiation to the entire body or large portions of it, blood changes consist of destruction of white cells, creating leukemia.

Actually, the doctor would be guilty of gross negligence if he permitted himself to develop any symptoms of over-exposure. In the average practice, there is not enough use of the x-ray equipment to approach sufficient radiation of a damaging character. Those active in institutional radiography, where many exposures are being conducted, run the greatest risk of over-exposure.

In the usual radiographic examination, the amount of radiation received by the patient is but a fraction of the dose that would be necessary to produce bodily harm. He should be asked, however, if he has been exposed to x-radiation recently, and, if repeated exposures are to be given in any one area, caution should be exercised to avoid excess.

Protective Measures. In order to prevent damage by radiation, a systematic check against any phase of excess must be carried out. All personnel should be advised concerning protective measures and rigid rules for their enforcement should be established.

The x-ray generating equipment itself should afford the least possible hazard. A protective filter of aluminum is usually provided to absorb the excessive soft "burning" emanation. Most x-ray tubes are contained in a ray-proof housing that only permits radiation to be emitted from the portal designed for this pur-

pose. This housing is effective within a range of approximately 1.0 per cent. The line focus of most x-ray tubes directs the primary beam in a reasonably straight course, thereby reducing the area of radiation. The radiographer should wear a lead rubber apron to protect himself from general body over-exposure. This reduces the effective absorption to a minimum. Under no circumstances should the operator ever place himself in the direct path of the primary ray.

A word of precaution in regard to determining the tube anode-to-skin distance is offered because the actual distance can be deceiving; i e., in making a dorsoplantar exposure in the static attitude, the distance should be computed from the tube anode to the leg, where the primary beam will first strike, rather than to the dorsum of the foot. Less than 12″ target to skin is dangerous.

For practical purposes there is ample latitude for even extensive radiographic examinations before the tolerance is exceeded. Each unit should be calibrated

Consideration should be given to neighboring offices If the roentgen department is located above a room containing fixed workers who might receive radiation through the floor, protection should be afforded by proper ray-proofing of the room. Likewise, the walls should be ray-proofed if there is any attendant danger

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Chapter XIV

Roentgen Equipment for Foot Examination

SELECTION OF AN X-RAY UNIT

The selection of equipment for radiographing the foot is a comparatively simple matter. Units specifically designed for the purpose are on the market today. A number of years ago this author designed a foot x-ray unit which is still in vogue. This unit consists of a fixed tube-stand attached to the wall at the top and to the floor at its base. Extreme flexibility is obtained through a tube-arm that is segmented and hinged in such a manner that the tube-head may be moved through a five-foot range, thus allowing for both front and back positioning. This innate flexibility eliminates the need for a mobile base. The counter-balanced tube-arm travels up and down from its top to the floor with finger-tip control. The tube itself rotates completely on a vertical axis and also carries through a complete range of motion on a horizontal axis. Unquestionably, this unit provides a maximum of maneuverability in a minimum of space. A fine focal spot tube that may be operated from 0 to 20 milliamperes is used. A convenient adjusting knob provides three different amounts of kilovoltage: 45 Kv. P. at low for a small foot, 55 Kv. P. at medium for a medium sized foot, and 65 Kv. P. at high for a large foot. These radiographic facilities insure high quality foot radiographs (Fig. 233).

Appraisals of posture from antero-posterior pelvic outlines may be radiographed with this unit in conjunction with high-speed intensifying screens and a stationary grid. However, good posture studies require lateral views of the pelvis, and more highly powered equipment is necessary to achieve satisfactory radiographs. A rotating anode tube, or at least a unit of 30 Ma., 100 Kv. P. capacity is preferred.

Radiography of the foot does not require high-powered equipment because the largest foot seldom exceeds 12 cm, and 65 Kv. P. should supply ample penetration even when it is necessary to radiograph through a plaster cast. Low operating intensities make it possible to use a fine focal point x-ray tube which accentuates bone detail and produces superb foot radiographs. It is interesting to note that radiographs performed with high-powered units with broad focus tubes may produce results inferior in detail

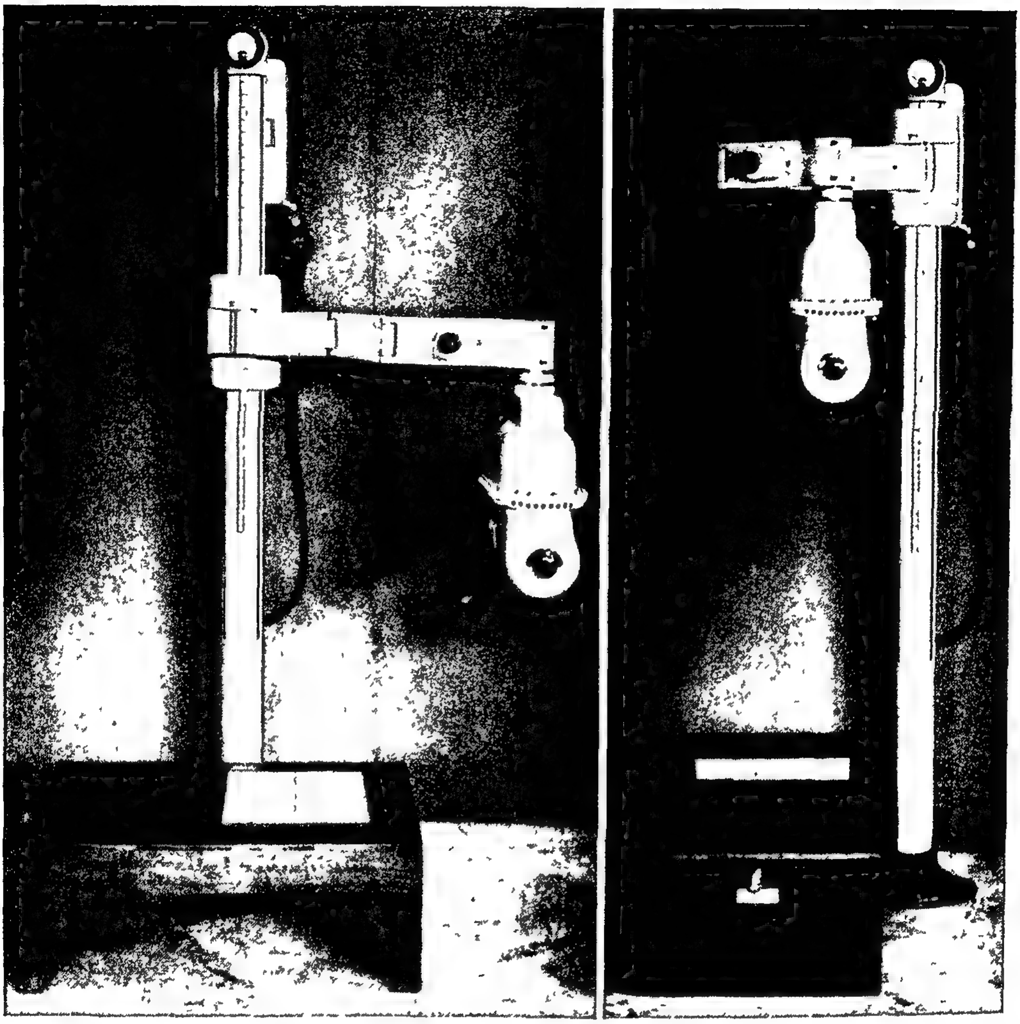

FIG 233 (Left) FOOT X-RAY UNIT Ortho-x-poser in foreground Flexibility of tube arm shown by tube position (Courtesy of Ritter Co , Inc.).
FIG 234 (Right) FOOT X-RAY UNIT. Compactly folded against wall when not in use. Minimum floor space needed (Courtesy of Ritter Co , Inc.)

There is a group of x-ray machines on the market that might fulfill the radiographic essentials; e.g , portable models, small mobile or bedside units and even dental units; however, they lack the refinements that make for convenience and properly performed radiographs. If a unit is cumbersome, unwieldy, and difficult to adjust, it is worthless

The unit designed by the author has been stripped of all unnecessary accouterments so that it may be mounted in a corner and, together with the examining stand (Ortho-x-poser), utilize a space not more than four feet square (Figs. 233–234). The specific flexibility of the tube-arm is its outstanding feature for achieving accurate and rapid radiographic positions

Safety must be considered in purchasing x-ray equipment. Today, all units are shock-free through insulation of the high voltage within the housing of the tube. Older models had dangerous, exposed high tension wires. The tube housing also safely restricts stray radiation by permitting it to emanate only from the portal of the tube housing

The manner in which the x-ray tube is cooled distinguishes two classes of equipment. Units used for foot radiography are cooled either by air or by oil. Over 99 per cent of the energy developed within an x-ray tube is converted into heat. Most of this heat converges upon the target of the anode in the x-ray tube. The anode of the tube is made of copper or some other heat conducting element that carries the heat to the end of the tube where some form of metal radiator is attached. This system may be adequately cooled either by an air chamber around the tube or by immersion of the tube in oil which dissipates the heat. In ordinary office radiography, there is little likelihood of tube damage due to a heat factor, regardless of the method of cooling the tube The most important consideration for the user is accessibility of the tube for service or cleaning.

The timing device, although an integral part of x-ray generating equipment operation, is sometimes considered an accessory. There are two types. The mechanical type is put into action by turning a dial to the desired time of exposure. This, in turn, winds a spring that provides the power to set the clock-like mechanism in motion. The other type is the electro-synchronous timer which uses the 60 cycle alternating electrical current as its motivating force. Both types are accurate and reliable.

One of the most important features of any x-ray generating equipment is a protractor scale to define the angle of tube adjustment. Without this simple but most important indicator, it is impossible to know at what angle an x-ray is being projected. The basis of all good foot radiography is accurate positioning of the central ray of the x-ray beam; consequently, an accurate device for giving the angle of projection is absolutely necessary.

There is likelihood of our present types of x-ray equipment being out-moded in the future by radio-active generators capable of producing radiographs. This prediction is substantiated by reports of experimental models utilizing radioactive thulium

Below is a summary in outline form of the factors to be considered in choosing radiographic equipment

Essential Features in Equipment Needed for Good Foot Radiography

(1) Freedom from shock.
(2) Fine focal point tube (1 5 to 2 5 mm).
(3) Continuous operating rating of at least 12 sec at 10 Ma , 45 Kv. P.
(4) Radiographic capacity of at least 10 Ma. at 65 Kv. P.
(5) Wall mounted tube-stand with flexible arm, or mobile base type.
(6) Tube-arm that can be lowered to within ten inches of the floor.
(7) Flexible adjustability of the tube.
(8) Protractor scale to define the angle of tube alignment.
(9) Reliable timer.

Other Desirable Features

(1) Variable Ma. and Kv.
(2) Automatic circuit-breaker.
(3) Counter-balanced tube-stand.
(4) Voltage compensator.

THE X-RAY EXAMINING STAND (ORTHO-X-POSER)

In the roentgen department of most hospitals, the conventional method of producing a foot radiograph consists of having the patient lie on the x-ray examining table, placing a loaded cassette under the foot, and instituting the exposure For many years, the foot specialist has modified this method by having the patient sit in the treatment chair, placing the loaded film-holder under the foot on the footrest of the chair, and making the exposure.

In cases of traumatic or pathologic lesions affecting the feet, the patient is incapable of comfortably sustaining body weight; consequently, radiography of the foot in recumbent attitudes has become an accepted routine (Fig. 235). The

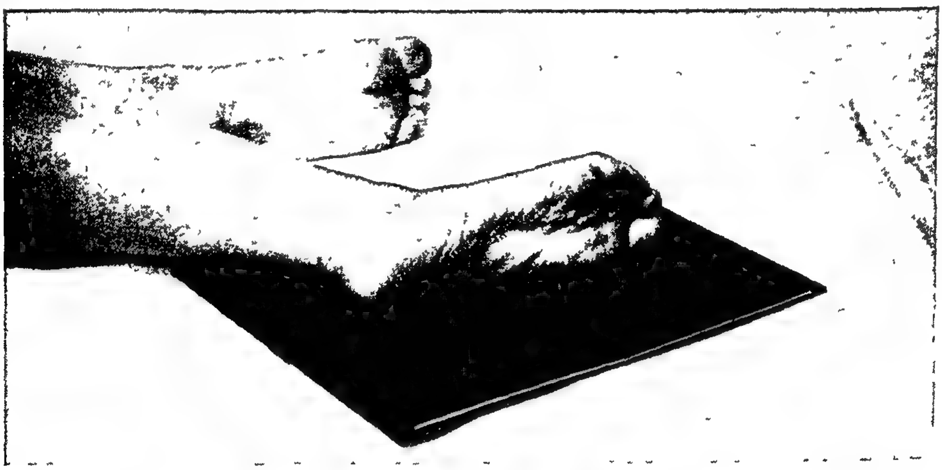

Fig 235 Recumbent Foot Position

Fig. 236. Radiograph of Recumbent Foot.

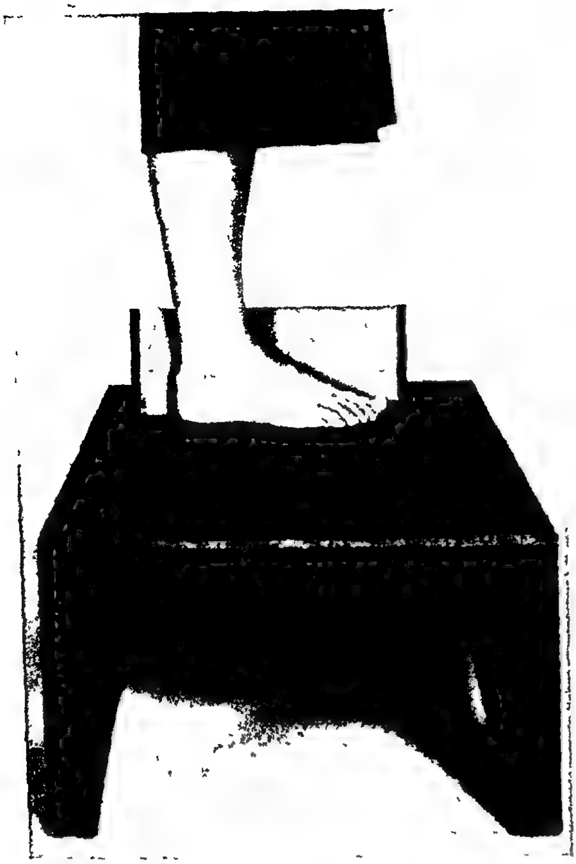

FIG. 237. STANDING FOOT POSITION.

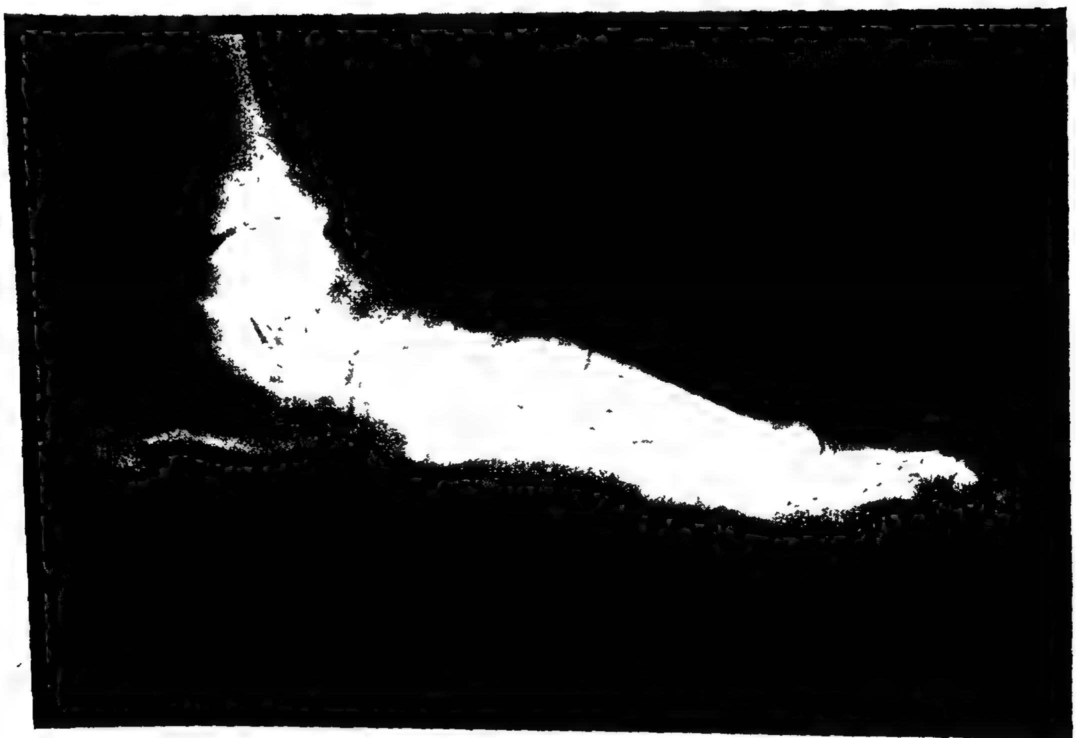

FIG. 238 RADIOGRAPH OF STANDING FOOT. Same case as Fig 236

position does not, however, provide an accurate visualization of the structural status of the foot under the stress and strain of natural body weight. For example, little value can be attached to a radiograph so obtained of a case exhibiting depression of the longitudinal arch because the relaxed foot assumes an

arched contour regardless of its orthopedic condition (Fig. 236). A radiograph of this same foot made with the patient bearing weight on it visualizes the characteristic changes in alignment, thereby aiding diagnosis, treatment, and prognosis (Fig. 237, 238). Thus, it is obvious that a special approach to foot radiography must be made.

In addition to requiring radiographs produced while the patient is in standing position, there should be a standard projection for these exposures A standard position is one that may be duplicated at any time. This is of inestimable value in establishing a uniform procedure that will produce foot radiographs which any practitioner, following standard position technique, can interpret. Also, a uniform basis for research is thus established.

Ortho-x-poser. This apparatus and the technique used with it were devised by the author to fulfill the special needs of foot radiography; that is, radiographs with the patient standing and also standard positions for all exposures. The name of the device was coined by using the combinations "Ortho" (correct alignment), "x" (x-ray), and "poser" (position) Many features were incorporated in the device to facilitate foot radiography (Fig 239). In order to explain the advantages of this device over conventional x-ray examination tables, a history of its development will be given

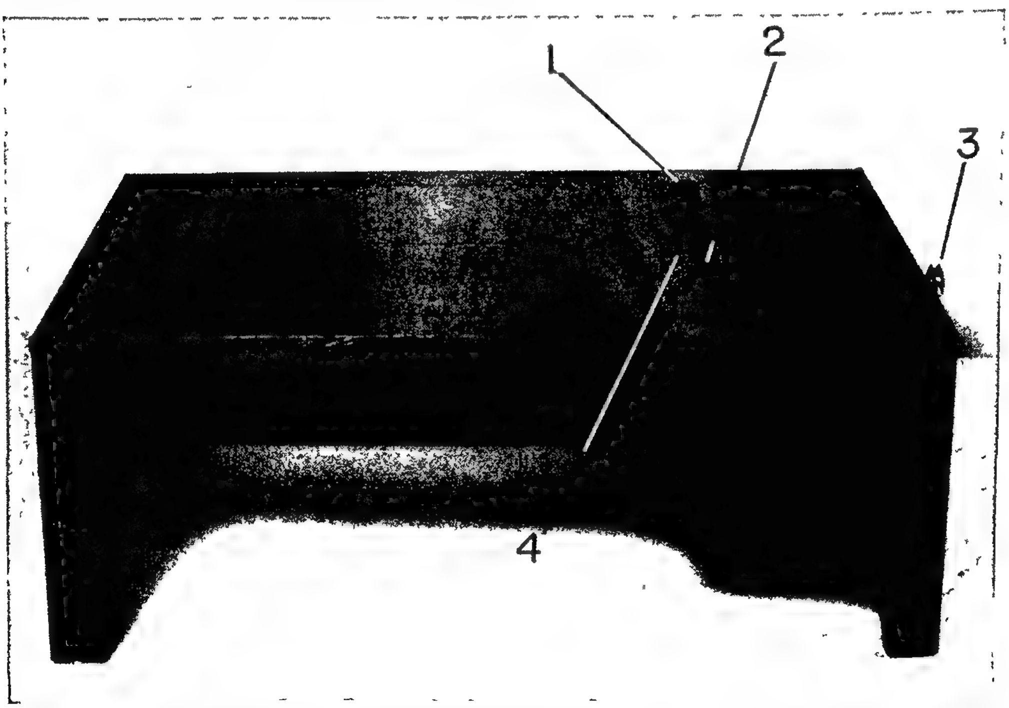

Fig 239 Ortho-x-poser—Foot X-ray Examination Stand *Structural Features* (1) Radiation-proof well to protect film in lateral exposures Provision for ray to under-cut foot (2) Cassette engaging bar holds film-holder in fixed vertical position (3) Pull-knob used to engage bar against film-holder (4) Foot position scale in one inch gradations, in front of film well, insures duplication of film position for stereoscopy Guide lines are present on front of device to assist in positioning central ray. Fixed depth of protection in well equal to one-half the 10 in. dimension of either 8 in x 10 in or 10 in x 12 in exposure holder. Cassette holder for vertical or horizontal position Durable cabinet to withstand hard clinical use with patients of maximum weight Easy to mount—11 in high (Ritter Co Inc)

Conventional x-ray examining tables and makeshift x-ray examining chairs are both impractical and inadequate for radiographing the foot in a natural standing position. In standing, the patient is elevated to a dizzy height not conducive to safety. On the other hand, when the patient stands on the floor, proper alignment of the foot with the film can not be conveniently provided. In no case can the exposures be duplicated with any fidelity. To overcome these difficulties, a cabinet 11 in. high was devised. The patient could then stand upon this comfortably and with a sense of security.

Securing a lateral view of the weight-bearing foot presented the problem of holding the x-ray film-holder in a vertical position that could later be duplicated. This difficulty was overcome by using a tension bar that automatically engaged the cassette or cardboard exposure holder (Fig. 240).

Inasmuch as the entire area of a 10 in. x 12 in. film is not fully utilized when a lateral view of the foot is recorded, a radiation-proof film-well was incorporated in the cabinet to prevent exposure of the excess portion of the film With this arrangement, it is possible to make several exposures on the same film, thereby providing film economy. Of still greater importance, the complete x-ray examination of the foot on the same film is a great convenience in interpretation, since the whole story is before the examiner at the same time In shielding the film against direct radiation, provision is made for laterally projected x-rays to "undercut" the foot. This feature displays on the radiograph a complete outline of flesh under the weight-bearing bones instead of the "cut-off foot" appearance that was always recorded in prior examining procedures. Provisions to accommodate any size film from the small 2¼ in. x 3 in. size, used for single toe work, up to the 10 in. x 12 in. film, used in posture studies in the ray-proof well, were made.

Ample room is provided on top of the cabinet so that the position of the film can be changed without the patient having to step off the device. A one-inch scale in front of the film-well and at the end of the Ortho-x-poser assists in centering the ray for proper focus This scale makes lateral stereoscopy of the foot possible.

Another very important feature that has been automatically achieved by this device is immobilization of the feet by the act of standing Body sway occurs mostly above the knees and that occurring between the knee and the foot may be voluntarily controlled quite well by the patient, while the foot itself remains immobile The necessity for use of the cumbersome method of immobilizing the foot with sandbags is eliminated The x-ray technician realizes that distortion due to movement of the part is a great factor to overcome and that overcoming it reduces the necessity of retakes to a minimum.

Although this device was primarily developed for weight-supporting radiography, it may also be used for recumbent radiography In cases of trauma or painful foot pathology, the patient is seated at the side of the Ortho-x-poser on a high stool and the foot placed on the device in a resting position. Although it is ordinarily difficult to overcome the tremor present in a severely injured extremity, especially when examining on a table, it is surprising how easily the weight of the leg, steadied by the patient's hands, insures an immobilized foot.

FIG 240 PLACEMENT OF FILM-HOLDER IN RADIATION-PROOF WELL

HOUSING THE EQUIPMENT

Equipment that renders a service as valuable to the patient and the doctor as does x-ray equipment merits space and location that will dignify the service Often the equipment is so inconveniently located and so difficult to maneuver into position that the doctor postpones x-ray examinations that should be performed The patient is far more critical of the office and its function than the doctor realizes. X-ray equipment, like all other equipment, should be housed in an attractive and accessible location

The ideal location for the x-ray unit is in the consultation-examination room. In practice, such a room is slowly becoming a reality. Actually, the consultation room should be an examining room with all diagnostic equipment and an examining chair accessible A consultation room limited to a desk and chair for subjective questioning is of little use for foot orthopedic diagnosis.

A small amount of space in a corner of the room is all that is required to house the x-ray generating equipment and the Ortho-x-poser Since the Ortho-x-poser is an independent accessory, it may be stood on end when not in use if space is at a premium The wall-mounted type of unit uses the least space, since the tube-stand is located 10 in. from one wall and 12 in from the other in a corner. The Ortho-x-poser is placed diagonally in front of the tube-stand and any exposure may be made within a floor space of four square feet

The average doctor is not likely to be able to provide space for a consultation-examination room from his usual office space if such a room is not already in existence when he acquires x-ray equipment. However, no matter how modest

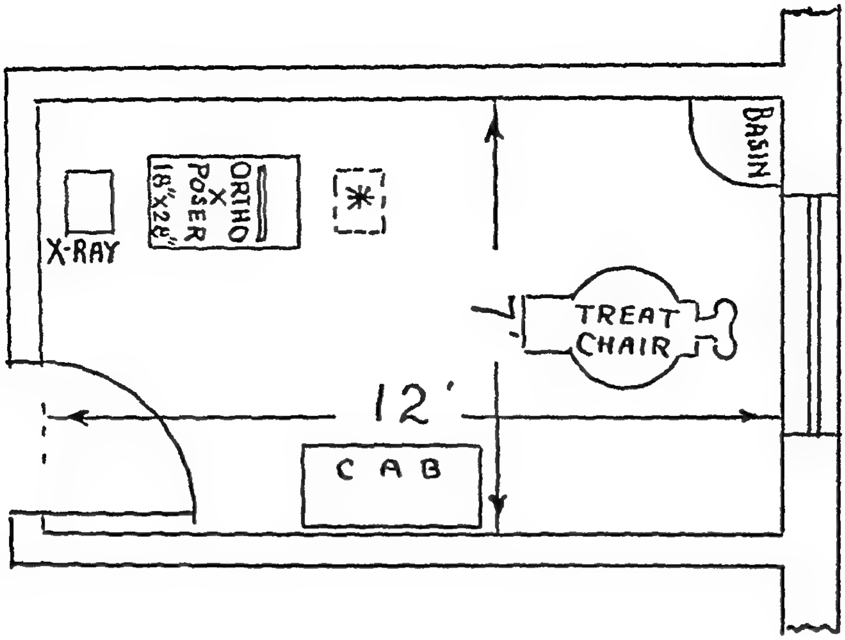

FIG 241 X-RAY EQUIPMENT IN THE EXAMINATION ROOM.

the office plan, every foot specialist has a potential consultation-examination room in the form of a treatment room. The x-ray unit may be located in the corner of the room in front of the treatment chair. The space ordinarily used for the operator's chair may be used for the Ortho-x-poser. When not in use, the Ortho-x-poser may be stood on end in back or alongside of the treatment chair. Of course, an arrangement of this kind applies to the one-room office (Fig. 241).

The doctor should note that placement of the equipment in a treatment room that is in constant use presents a problem, since the doctor will have to wait until the room is free before he can make an examination. Often, a corridor provides room for the installation and proves to be very convenient since it uses what would otherwise be non-productive space.

When the excrescence exploratory examination is used as a routine admission procedure, the x-ray unit is a logical complement to the hydro-therapy room, provided that hydro-therapy is also used as a preparation for excrescence treatment. It is very convenient to be able to admit the patient to the x-ray location, complete the exploratory examination, and then institute the hydro-therapy preparation The patient is then shod in paper slippers and transferred to the treatment room. The hydro-therapy stool is convenient as an accessory chair when examining the foot in a recumbent attitude when there is an injury or a painful pathological condition.

Still another plan is to use a small cubicle exclusively for x-ray work. Approximately 5 ft. x 6 ft. should be allowed so that a high chair may be included with the equipment in the room.

Many doctors have an office consisting of several rooms to assist them in rendering a variety of services At the other extreme is the one-room office. In the long run, placement of x-ray equipment is an individual problem that every doctor must solve after study of his own individual conditions.

INSTALLING THE EQUIPMENT

The installation of the x-ray equipment should be the responsibility of the dealer from whom the equipment is purchased. Unfortunately, some dealers have not been properly schooled in the details of connecting an x-ray machine electrically and in the other factors that should be considered. For that reason, the following discussion is included to serve as a guide for the doctor to consult in checking up on an x-ray installation.

Good radiographs can be produced only when the x-ray generator is functioning in the way in which the manufacturer intended it to function. This depends, primarily, on the unit receiving the proper electrical current from the source of supply. Local conditions vary greatly in regard to the amount of voltage supplied for the connection of an x-ray unit. The first step is to consult the local power company to determine the actual line voltage that can be expected at the location in question. It is also important to find out if there is any likelihood of fluctuation due to excessive use of current in the neighboring area. If excessive, fluctuation in voltage will produce uncertain radiographic results. After determining the amount of line voltage supplied to the location, the data supplied with the unit should be consulted to see if the voltage is acceptable for its use. If it is not, some simple adjustment must be made so that the unit can use the voltage and supply the desired x-ray energy. Most x-ray units are provided with several electrical connections so that any one of several different line voltages may be used.

In this connection, the doctor must realize that it is a question of the quality of the radiograph rather than one of damage to the x-ray generating equipment. A slip-shod installation done with little regard for the proper supply of line voltage will not prevent the x-ray unit from operating. It will produce radiographs. However, under these circumstances, the technique of exposure factors furnished by the manufacturer will not be reliable. Suppose the line voltage is greater than the amount required by the unit. Then, more x-ray energy is produced for each exposure; consequently, the finished radiograph will be overexposed. The unwary doctor tries to account for the resulting poor radiograph. He may blame any one of several factors: faulty processing, faulty x-ray unit, faulty exposure factor chart, and even faulty judgment on his part in the selection of the factors used. A tedious rechecking of all factors by performing a second exposure results in the same poor radiograph. The doctor then follows one of two courses of action—he either makes an adjustment in the amount of exposure and alters the exposure chart supplied by the manufacturer, or he condemns the x-ray unit. If the latter action is pursued, the faulty supply of line voltage will probably be discovered and the proper adjustment made. If the doctor alters the exposure chart, he will have to adjust the factors for every exposure listed. This is quite an undertaking for a novice. This has happened. The incorrect basic line voltage is the responsible factor.

Every effort should be made to supply an even, unrestricted electric current for the x-ray unit. A separate circuit from the main supply carried to the x-ray receptacle by a number 10 size wire is needed. If this is done, there will be no possibility of several pieces of office equipment drawing upon the voltage sup-

plied to the unit. The electrician assisting with the installation can take care of these details.

Proper grounding of the x-ray unit is of the utmost importance, because it is this grounding that protects the patient and operator against electrical shock if any defect should arise in the unit during high-voltage production. Grounding to an electrical conduit is inadequate. Rather, a wire from the receptacle should be connected to a cold water supply pipe.

To prevent the common but damaging mistake of forgetting to turn off the x-ray unit after use, a 15 ampere double pole switch with pilot light should be placed in the supply line at a conspicuous location on the wall. It then becomes necessary to turn on this switch which in turn will light up the brilliant ruby pilot light, before the x-ray machine can receive electrical current. Likewise, it will remind the operator to turn the current off. Most x-ray units are supplied with a pilot light.

TESTING THE EQUIPMENT

X-ray equipment should be thoroughly tested. This includes a fairly large number of items.

All the following mechanical adjustments on the unit should be checked: up-and-down movement of the tube-arm on the tube-shaft, counter-balance of the tube-arm, screws set for various fixations, in-and-out movement of the tube-head, rotation of the tube-head, rotation of the tube, etc

The timer should be checked with a second sweep watch

A test of the electrical operation of the unit is also essential The supply line is plugged into the supply receptacle, with ground included.

A careful survey of the adjusting instruments and the indicating meters should be made. They may vary with different manufacturers' models. The recommended radiographic technique utilizes a simple set of controls

The lever that indicates the kilovoltage should be adjustable to High (65 Kv. P.), Medium (55 Kv P.), and Low (45 Kv. P) As soon as the main switch for operation of the unit is turned on, kilovoltage is being produced and is available for x-ray production. The kilovoltage may be shown on a meter that has been calibrated at the factory or it may be merely indicated by step numbers at the control lever. These numbers correspond to a kilovoltage shown on a chart supplied by the maker Again, the kilovoltage may be simply indicated by "H," "M," "L," corresponding to 65 Kv. P., 55 Kv P., and 45 Kv. P. *The kilovoltage control lever should not be changed while the x-ray tube is in operation.* The control lever should be precisely set. If it is turned beyond the mark, the machine may not function, with the result that the operator needlessly fears tube failure or some other disorder

Milliamperage is not produced until the x-ray tube is set into operation by the timing device switch. The most critical adjustment on the x-ray machine consists of regulating this milliamperage To maintain proper milliamperage, an adjustment of the milliamperage control must be made for every change made in kilovoltage. Actually, in the technique that will be recommended, the milliamperage must remain constant at 10 milliamperes The lower the kilo-

voltage setting, the higher the milliamperage control must be turned to obtain the constant reading.

To simplify operation of the x-ray machine, it is wise to make a calibration chart for the settings making up the relationship between kilovoltage and milliamperage.

Calibration Chart for X-ray Machine

Ma Control Setting

Kv P. Setting	*Ma. Setting*
High 65	10
Medium 55	10
Low 45	10

The technique of this calibration is relatively simple.

(1) Turn the x-ray beam downward to avoid exposing anyone to the rays.

(2) Place the Kv. P. control on *low* (45 Kv. P.) and turn the milliampere control to 0.

(3) Turn the dial on the time switch to the left until it stops. Then press the button and, while the time switch is running, turn the milliampere control until the milliammeter reads 10. Record the milliampere control setting on the calibration chart opposite *low*. Then turn the Kv. P. control to *medium* (55 Kv. P.). Start the time switch and advance the milliampere control until the milliammeter reads 10. Then record the setting on the calibration chart opposite *medium*. Place the Kv. P. control on *high* (65 Kv. P.) and repeat the procedure.

When the correct milliampere control setting for each of the three Kv. P. control positions has been determined, it will be found to vary only slightly on subsequent exposures, although some variations resulting from fluctuation of line voltage may be expected This should not be so great as to influence the radiograph objectionably.

The equipment should now be ready for actual radiographic work. After careful study of the chapter on radiographic technique, a subject should be chosen and lateral and dorso-plantar views performed according to the exposure factor chart. If meticulous attention has been paid to the installation and testing details, the first exposures should be successful.

Attention must be drawn to the fact that some x-ray units are manufactured with fixed kilovoltage and fixed milliamperage settings. If the line voltage required by the unit is provided by the doctor through proper electrical installation, the unit should perform with the milliamperage and kilovoltage factors specified by the manufacturer. Charts for various set factors are given in the chapter on radiographic technique (Chap. XV). These should be consulted when this type of equipment is to be tested

After the electrical soundness of the installation is assured, attention may be directed to the physical arrangements It is assumed, of course, that the practitioner has followed the suggestions for housing the equipment and that a suitable location has been selected

If a fixed tube-stand type of x-ray unit is to be installed, it should be firmly attached to the wall so that it will not become loose or jar out of alignment.

Great care must be taken to be sure that the tube-stand is perfectly vertical. This should be checked by using both a plumb bob and a spirit level from all sides.

The basis of good positioning technique, especially standardized technique, consists of a perfectly vertical tube-stand and a perfectly level examining stand. These factors can be achieved easily if the floor is perfectly level. If this is the case, the examining stand may be placed in convenient relationship to the x-ray unit and the x-ray tube should be perfectly aligned with the protractor for accurate projection to the film in or on the examining stand. If the floor is not level, the Ortho-x-poser should be placed in a location convenient to the x-ray unit and then, by the use of lifts under the low legs, it should be adjusted until a builder's level shows it to be perfectly level This location should be marked by pressing a thumb tack into the floor beside each of the four legs. This makes placing the examining stand in the proper position a very simple matter. The lift necessary to make the stand level should be permanently attached to the stand.

EXPOSURE ACCESSORIES

The Radiographic Cone. When the roentgen ray leaves the focal spot of the x-ray tube, the various wave-lengths of the ray are projected in many tangents Those that are perpendicular to the tube are known as central rays and those traveling at a wide tangent are known as divergent rays. The more centralized and localized the x-ray beam, the more precise the detail in the finished radiograph. A cone-shaped piece of metal may be attached to the x-ray tube head to limit the x-ray beam to an optimum group of radiation. Since roentgen rays cannot be focused, this cannot be achieved by focusing the ray as one would focus rays of light with a glass lens The radiographic cone limits the divergent radiation by absorbing any radiation that strikes its walls. The more central rays leave the portal of the cone unobstructed. There is no intensification of the x-ray beam by the radiographic cone. It merely permits the most useful form of radiation to reach the part under roentgen examination

In limiting the effective radiation, the cone also limits the scope of radiation. Often when the cone is used, there is not sufficient scope of radiation to cover the entire film and an area of unexposed film silhouettes the portion that has received the effective radiation This is known as "cone cutting" and can prove embarrassing when a portion of the part under examination falls into the unexposed area. The doctor should familiarize himself with the size of the scope of radiation at the usual target-to-film distance. Once this is known, care must be exercised in focusing the ray to be sure that the part is within the scope of effective radiation.

Actually the cone, when properly enscribed with guide lines, is an effective means for lining up the central ray with the part under examination It represents the sighting device for the x-ray tube. This is especially true when using it in conjunction with the Ortho-x-poser.

Radiographic cones are necessary to reduce scattered radiation when one is

radiographing heavy parts of the body and when plaster of Paris casts have been applied. The reduction of scattered radiation is mainly a matter of reducing the amount of divergent rays within the tissue rather than one of absorbing any of the actual scattered radiation.

Lead Shields. In order to compose several views of a part on the same film. it is a simple matter to use one or more appropriately sized lead shields to protect the film during the series of exposures The lead will provide protection by absorbing the roentgen rays before they reach the film.

A thickness of 1 5 mm. of lead or its equivalent in ray protection should be used to insure satisfactory results. Half-film blocks are supplied in sizes that protect exactly half the film Two half-film blocks must be obtained for each film size used—one to protect the length of the film and the other to protect the width. A 10 in. × 12 in. film would require a shield 5 in. × 12 in. for length protection and 6 in. × 10 in. for width protection.

Lead shields may be covered by plastic to keep them clean and of nice appearance. A patient is a bit hesitant about standing on a bent, dented, dark-colored piece of cold lead. Leaded rubber may be placed on the film-holder during dorso-plantar exposures but will not be found stiff enough to stand when the film-holder is held in a vertical position for lateral exposures.

Cardboard Film Holders. X-ray film is very sensitive to light rays. Consequently, it is necessary to place the film in a holder so that it may be handled during the examination. The ordinary cardboard film-holder is perfect for foot roentgenology. It consists of two heavy sheets of cardboard that are fastened together with a cloth hinge at one end and closed by a metal hasp at the other end. A heavy orange-colored paper envelope is fastened between the cardboards The envelope, when folded properly, affords complete protection for the film from stray light-leaks If improperly folded, the processed film will show a characteristic pattern on the center of the film where light has crept in from each side and exposed a portion of the film Proper loading of the cardboard holder consists of placing the film in the main portion of the envelope, carrying over the big flap, and folding the sides The end then flaps in place.

One side of the cardboard holder is designated as the film side and is divided into four equal quadrants by printed lines. This side of the holder should always be directed toward the x-ray film The printed lines assist the operator in laying the lead shields on exactly the right portion of the film when making multiple exposures on one film

The opposite side of the cardboard holder is designated as lead-backed In addition to the cardboard, a thin layer of lead is incorporated behind the film envelope. This lead backing prevents secondary radiation arising from any substance in back or under the cardboard holder from reaching the film It does not intensify the effect of the x-ray upon the film

Cardboard film-holders are supplied for the standard film sizes A liberal supply of holders of the most usable sizes should be purchased In foot radiography, the 5 in × 7 in size and the 10 in × 12 in size are the most acceptable With a good supply of loaded film-holders on hand, the doctor may conduct several x-ray examinations during the course of a day and allow the exposed films to accumulate until it is convenient to process them

Flexible Film Holders. Plastic is now used for film-holders and is more durable than cardboard. This type is useful in connection with imprint radiographic technique.

Cassettes And Intensifying Screens. A cassette is a film-holder of very durable construction, usually of steel or aluminum. Intensifying screens may be mounted within a cassette on both back and front if desired. It would be impossible to achieve this with a cardboard holder Intensifying screens are chemically treated with a substance that is known to fluoresce when the x-ray strikes it. This property is utilized by recording the fluorescing visible light upon a film especially balanced to react with it. Very short exposure times are possible when intensifying screens are utilized. This is advantageous when radiographing infants' feet since it averts distortion due to movements of the feet. Intensification is also of value when radiographing heavy parts.

However, under ordinary circumstances, foot radiography does not require cassettes with intensifying screens. They are costly, cumbersome, and fragile. Intensifying screens deteriorate with age. They must be mounted very carefully to insure even contact with the film for proper detail in the radiograph. Dirty screens will mar radiographic results since dirt blocks the fluorescent light. Unless the doctor does a great amount of pediatric work or wishes to have a cassette with screens on hand for an occasional heavy-part radiograph, there is little need to invest in them.

Film Marking Devices. Proper identification of every radiograph is as important as producing a good diagnostic radiograph. This is a legal responsibility to the patient and to the doctor. Proper identification consists of the patient's name (or serial number if the patient has been recorded in a master log book), the date of examination, the doctor's name and location, and a designation indicating whether the radiograph is of the left or right foot. Even trial exposures made while testing equipment should be properly identified.

There are several methods of recording the identification data on the film. It may be exposed directly on the film at the time of x-ray exposure by affixing a marker composed of lead letters carrying the necessary legend This is a very accurate method but a great deal of time is consumed in selecting the little lead letters and applying them to the marker to form the legend. Actually, when this method is used, it takes more office time to compose the identification than to carry out a lengthy radiographic examination.

A simpler marking device consists of a series of stenciled numbers on wheels which may be revolved so as to form the serial number for the patient The date is composed with lead letters The doctor's name and location is stenciled into the marker by the maker and does not have to be composed by the doctor. This device is in wide use but has the following disadvantages: the stencil wheels have a faculty of moving out of place, causing faulty numbering, and the marker is rather bulky and wastes too much valuable film.

The most effective identification is achieved by protecting a portion of the film from radiation by affixing a piece of $\frac{1}{16}$ in lead within the cardboard holder and printing the identification legend upon this reserved area of film by means of visible light There are two types of identification printers The Chamberlain x-ray film identifier is essentially a reduction printer and copies the data

from a 2 in × 6 in. record card and prints it on a 1 in. × 3 in. space on the x-ray film. This type is rather costly for simple office use but has no peer for fidelity. The other type consists of a small metal chamber with a slot in the top into which a thin slip of paper on which the identification legend has been typed may be slipped. Another slot receives the corner of the film that has been reserved. A foot switch clamps the printer tightly around the film and turns on a light within the chamber, thereby printing the legend upon the film. The only disadvantage in using this device is the possibility of mixing the paper identification slips. This can be avoided by clipping each slip to the cardboard film holder with the clip that holds it together. If several exposures bear the same identification, care must be exercised to stack the holders together.

Identification of the right and left foot should be made independent of other identification. A lead "R" and "L" individually mounted on a small piece of adhesive tape should be handy at all times. Every time an exposure is made the mark should be applied. When radiographing both feet, it is not an acceptable practice to mark only one foot on the assumption that the unmarked foot is thereby identified.

In composing a series of exposures on one film, numerals are sometimes used to identify the sequence of the exposures. This is not strictly necessary.

Exposure Accessories Needed

(1) Cardboard film holders:
Two—5 in. × 7 in.
Twelve—10 in. × 12 in.
(2) Lead shields:
One—5 in. × 12 in.
One—6 in. × 10 in.
(3) Identification printing device
(4) Lead letters:
Six—"L" 's
Six—"R" 's

X-RAY FILM AND PAPER

X-Ray Film. The object of every x-ray examination (unless it is a purely fluoroscopic one) is to make a visible record of the part under examination so that it may be interpreted medically or mechanically. The most widely used medium for making this record is x-ray film, which is a sheet of transparent cellulose acetate that has been coated on either one or both sides with a gelatinous suspension of silver bromide that is sensitive to x-ray and light radiation

It is impossible to produce an emulsion sensitive to x-ray radiation without producing one that is also sensitive to light. Every x-ray film is, therefore, sensitive to light in some degree and must be handled under safe light conditions so the film will not be affected by unwanted light radiation

Screen Film The fact that x-ray film is sensitive to both light and x-ray

radiation gives rise to the application of intensifying screens that produce visible light when an x-ray beam strikes them. X-ray film known as screen film is produced to utilize the visible light to a maximum degree of efficiency. At the same time, x-ray radiation has an effect on the emulsion, and the sum of the two effects make up the final radiographic effect. It is obvious that when this film is exposed in an ordinary cardboard exposure holder, a long period of exposure by x-ray will be necessary to produce a radiograph. Even so, the final result will lack the characteristics intended for it when properly used with light intensification

No-screen Film. In recent years, there has been developed an x-ray film that is highly sensitive to the x-ray beam without the aid of any intensification. This film is particularly suitable for foot radiography because it produces a radiograph high in contrast and detail.

X-Ray Paper. Another x-ray recording medium that should receive attention is that known as x-ray paper. It consists of a heavy stock paper coated with a high quality emulsion on one side only. The emulsion is especially sensitive to light and may be used with intensifying screens. An equally good result may be obtained by its use in cardboard exposure holders if a longer period of exposure is used.

Like photographs, radiographs produced on x-ray paper may be viewed without the need of transillumination. Consequently, they are easy to chart for the appliance maker, easy to measure and appraise for shoe last and size, and easy to mount for visual education displays. Since only one side is used for the radiograph, the reverse side may be used for recording data pertinent to the case.

X-ray paper is especially suitable for patho-mechanical foot survey, excrescence exploratory examination, radiographic patterns for appliances, determination of shoe last and size, and visual education projects. Its only limitation is the identification of bone pathology *per se,* which should be recorded on film so that the contrast and detail may be enhanced by transillumination

Storage of X-Ray Film and Paper. A compartment lined with lead should be provided for the storage of all unprocessed film. This prevents scattered radiation from spoiling the stock. The compartment should be large enough to hold both film stock and the supply of loaded exposure holders. This arrangement is both convenient and safe.

Individually Packaged Film. A foreign manufacturer is packaging no-screen x-ray film in individual paper envelopes. This provides convenience and timesaving because there is no need to transfer the film to a separate film-holder.

THE PROCESSING DEPARTMENT

Provision of adequate facilities for processing radiographs is, of course, extremely important. Frequently it is more difficult to complete installation of processing facilities than to install x-ray generating equipment This postulates forethought. Attention must be paid to careful selection of a favorable site for the room, a good plan for the room, choice of the right processing tank, the proper type of plumbing, and adequate illumination and ventilation. Also, the room must be equipped with the proper processing accessories and supplies.

Selection of the Processing Room. A small room or closet may be used for the processing department. Running water and a drain should be nearby. The atmosphere must be dry if the radiographs are to dry properly. An even room temperature will facilitate keeping the temperature of the solutions within reasonable limits Ideally, the room should be located on an outside wall so that a ventilator can supply fresh air.

It is possible to combine the processing department with the mechanical orthopedics laboratory, the general supply room, the clinical laboratory, or a combination of these departments The undesirable effects of chemical odors and excessive humidity may be overcome by the use of a tight cover for the processing tank to shut off odors, an exhaust fan to remove them, and silica gel crystals to absorb the excess moisture.

The processing room must be accessible, since exposure holders are reloaded there and loaded exposure holders stored. If the room is remote from the office, the doctor is subjected to needless delay and aggravation. Thus it can be seen that a basement, for example, is not a very suitable location

Planning the Processing Room. To insure smooth operation, the processing department must be planned to work with maximum efficiency. Two working areas are necessary in every processing department. (1) A working surface, on which films may be loaded and unloaded from film-holders and where films may be loaded onto hangers for processing purposes, and (2) the processing tank, which contains the processing chemicals.

In addition to this essential working area, there should also be space for: (1) storage of film, (2) storage of film-holders, (3) storage of processing chemicals, and (4) storage of accessories.

If work is limited to foot radiography, there is no need for a large room devoted to processing Economy of space by careful design will reduce the space needed to a minimum (Fig 242)

One of the smallest processing rooms that can be pressed into service consists of a closet large enough to house a processing tank and allow one person to stand in front of that tank. A shelf above the tank can be used for the loading surface A higher shelf provides the necessary loading space A compartment lined with sheet lead can be constructed at the side of the top shelf for film storage. The tank should be placed on a low stand, just high enough to clear the drain tap, rather than upon the standard-height supports This arrangement makes it possible to have the working surface shelf at a convenient height above the tank The shelf should be high enough to permit transfer of the film-hangers from one compartment of the processing tank to another.

Linoleum, which is easily kept clean, can be used to cover working surfaces It is wise to have a dividing board between the film-loading area and the processing tank This will eliminate the possibility of spilling solution from the tank on the area

The Processing Tank. The tank must be large enough to accommodate 10 in. x 12 in film. Unfortunately, at this writing, processing tanks are not made to accommodate this size of film exclusively *The 14 in. x 17 in film-size tank is needed,* because the standard 8 in x 10 in film-size tank is too small The 8 in x

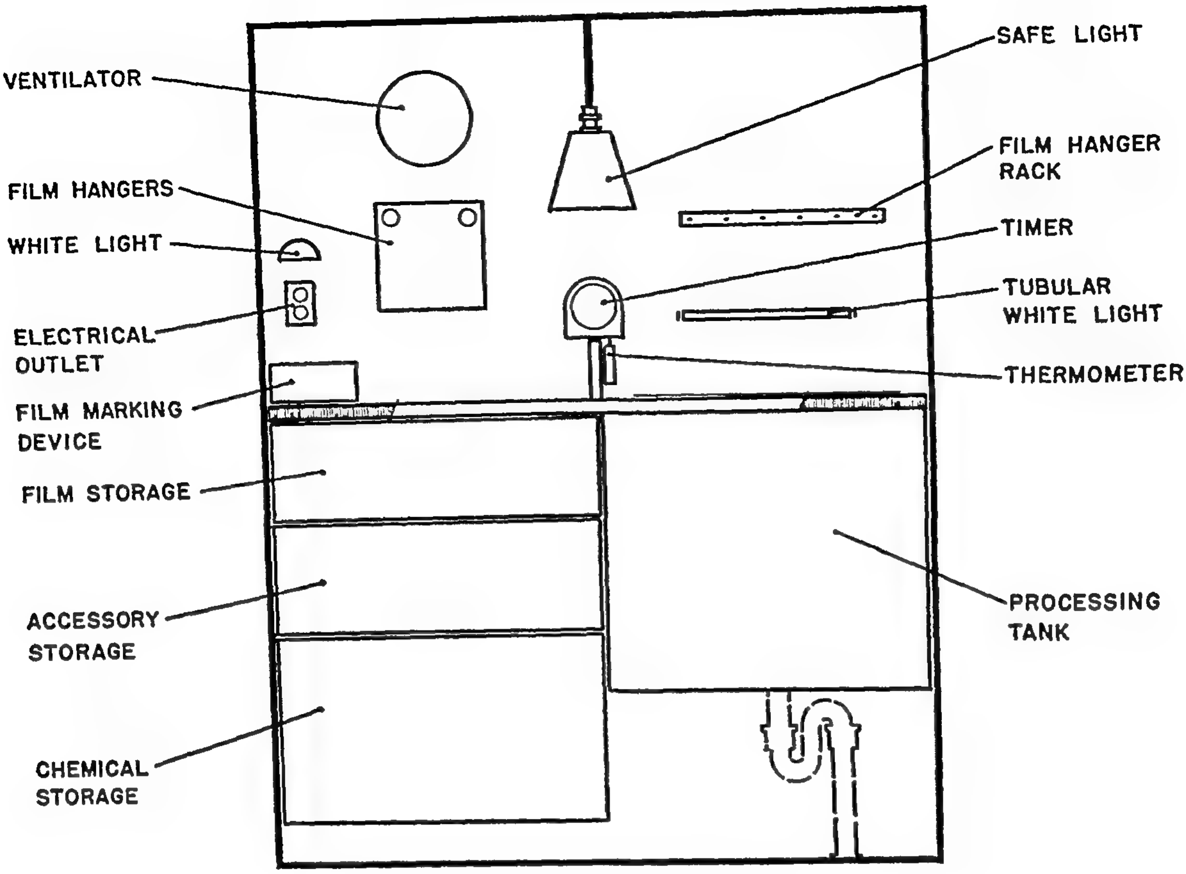

Fig 242 A Basic Processing Room

10 in. size film is inadequate for good foot radiography because many feet are longer than 10 inches In spite of this fact, the small tank is often sold to the unsuspecting customer with the idea of making the cost of the processing equipment low Unfortunately, the doctor soon learns that the tank is too small and is forced to replace it.

The 14 in x 17 in film-size tank is supplied with either 2½ or 5 gallon volume solution compartments. Most tanks contain three compartments—one for developing solution, one for overflow water, and one for fixing solution. It is advisable to install the larger tank if enough space is available. Twice as many films may be processed at one time in the larger tank This is an extremely important factor in saving time for, regardless of the number of films going through processing, the same amount of time is needed The doctor can appreciate this advantage when he is confronted by a stack of a dozen films awaiting processing. Approximately six films can be processed at one time in a 5 gallon tank, whereas only three can be processed in a 2½ gallon tank.

The lid to the processing tank should fit and should exclude light when films on hangers are hung and immersed in the processing solutions Some lids are not light-proof under these circumstances and should be avoided. With the proper lid in place, light may be turned on while the films are processing. The lid also helps to prevent evaporation of the developing solution Chemical odors will not permeate the room if the lid is kept in place at all times except when a film on a hanger is placed in the tank.

Plumbing. *A licensed plumber should be consulted before the processing room is constructed* Local plumbing codes are very strict. It would be pure folly to build an elaborate processing room and then to discover that the tank could not be connected to the plumbing system because of a restriction concerning the distance of the connection from the waste line

The processing tank should be supplied with hot and cold water and provided with a drain into the waste system. The water system serves a three-fold purpose: (1) it washes chemicals from the processed films, (2) it helps regulate the temperature of the processing solutions, and (3) it provides water for mixing solutions and cleaning purposes.

The doctor should be sure that the plumber places the valves for regulating the hot and cold water intake in an accessible place, preferably above and in back of the tank, so that they will be convenient. Mixed water temperatures can be adjusted to help maintain the processing solutions at the proper temperature by the conduction of the proper temperature through the walls of the adjacent compartments.

The spigot that supplies water for general purposes should be connected so as to provide mixed water temperature It should also be accessible so that a bucket, for instance, may be placed under it. A threaded spigot is convenient to connect a short length of hose for cleaning the tank compartments.

Processing Room Illumination. Since x-ray film is sensitive to light as well as to x-rays, it is imperative that unprocessed x-ray film be handled only in the presence of an illumination that will not affect the sensitized emulsion This type of light is known as "safe light" *Use safe light when handling unprocessed film,* while loading exposure holders prior to x-ray exposure, unloading the film from the holders after x-ray exposure, and throughout all other procedures until processing is completed X-ray paper is even more sensitive to light than x-radiation.

Non-safe white light may be used for general illumination of the processing room and for cursory examination of wet x-ray films.

Making the Processing Room Light-proof A number of precautions must be observed to exclude all light from the processing room so that a safe light may be secured The entrance to the room must be absolutely light-proof. Judicious use of weather-stripping around the door is usually sufficient to insure this. If there is a keyhole, it should be covered Locking devices should be placed on the inside of the door, so that someone cannot accidentally open it when the safe light is on Electrical switches controlling the white light must be inside the room so that someone on the outside cannot accidentally turn on the white light The switch for the white light should be separated from that for the safe light to prevent accidental unsafe illumination Windows and ventilators must be light-trapped

Color of the Walls of the Processing Room. If the processing room is absolutely light-proof, the walls may be painted any color desired. The idea that a processing room should be painted black is false The color black has little to do with the exclusion of actinic light.

The term "darkroom" is often applied to the processing room Although the

room is relatively dark when safe light is used, the term gained its wide use because in the past most processing rooms were painted black. This room should however, be as pleasant a place to work in as any other room. A semi-glossy finish of light green or grey is very pleasant for walls above the working surfaces. The working surfaces may be covered with dark linoleum. Areas below the working surfaces may be painted with acid-resisting paint.

Ventilation. Opening and closing the door permits access to sufficient fresh air to ventilate the small processing room. An active processing room, or one that is used for purposes other than processing, may be provided with a small exhaust fan. A light-proof grill must be incorporated in the door to admit air to take the place of the exhausted air. The exhaust fan must be light-trapped

Processing Room Accessories. Several articles are needed to provide complete facilities for processing radiographs. Although only those absolutely necessary will be described in detail, there are several special items that deserve mention. A processing tank heater that keeps the solution at a fixed temperature in cold weather is now available. Temperature-controlled processing tanks that maintain a fixed temperature during both hot and cold weather by means of a thermostatically controlled heating unit and a refrigerating unit can be obtained. Automatic film-driers that dry films in a short time by blowing hot air over them are available. Corner-cutting devices for films are also provided for the busy office.

Safe Lights. Safe light has been discussed at some length in our consideration of illumination of the processing room Since unsafe light would spoil films, the subject is of considerable importance.

Safe light is produced by encasing a low-wattage bulb and permitting the light from the bulb to be emitted through a colored filter that allows non-sensitizing rays to be thrown out. The device that combines these features is known as a safe light. Innumerable types are on the market. One that combines safe light controlled by one electrical switch and white light controlled by another seems ideal for small office use. Two of these units should be installed, one over the processing tank, where the white light may serve to illuminate wet films, and the other over the working surface where loading is done.

Safe lights must be light-proof and their intensity tested to determine the latitude of exposure for unexposed film under their illumination. This can be done by allowing a strip of film to be subjected to safe light for five minutes under the same film-to-safe-light distance that would ordinarily be used during processing. At each minute of the five minutes, a piece of paper should be moved along the film strip so that the film receives exposures of five, four, three, two and one minutes The strip is then processed and examined for any color gradation that would indicate excessive exposure.

Thermometer. There are two types of thermometers commonly used in the processing procedure. One consists of a glass tube that floats in the solution. The other type is a simple gauge mounted on a metal backing that is dipped into the solution for a reading of the temperature It is very durable.

Timer. An accurate timer is an absolute essential in every processing room, because processing time must be determined very carefully. Most timers are

powered by a spring that is wound by setting the time interval. An alarm rings at the end of the interval.

Identification Printer. Although discussed as an exposure accessory, this device is actually set up in the processing room. If the x-ray film is identified by printing an identification form on an unexposed portion of the film, an identification printer must be provided This device consists of a light contained in a light-proof chamber. When a corner of the film is slipped into the chamber along with the identification requisition, a switch is turned on and the legend is exposed on the film by visible light.

Film-Hangers A wire frame with clips for the four corners of the film is used to place the film in the processing solution. This frame is called a film-hanger.

Film-Hanger Storage Rack. A simple rack should be installed on the wall at a convenient location for the storage of the film-hangers. A rack for each film size is needed

Film-Hanger Drying Rack. After a film has been processed it must be hung up to dry. A rack containing holes into which the end of the film hanger may be placed is available. This rack should be mounted over the over-flow compartment of the processing tank so that excess water may drip into this compartment

Supplies. X-ray film and paper, which fall into the category of supplies, have been discussed Processing chemicals are the only other supplies needed. They consist of developing chemicals, fixation chemicals, and replenishing chemicals and they are available from several sources. In some of the larger cities, concerns specialize in a service that provides x-ray solutions for hospitals and individual doctors These concerns empty the tanks of old solution, clean them, provide fresh solution, fill the tanks, and leave a supply of replenishing solution to last until service is again needed Most of these concerns are reliable and one may be assured of their reputation if they supply a hospital under the endorsement of a radiologist.

Processing chemicals may be purchased in powder form and mixed by the user In this case, directions must be followed explicitly to achieve the proper results This is a bit tedious since the temperature of the water for mixing must be controlled very carefully. Also, considerable time is required to dissolve the chemicals Some claim better results from chemicals so prepared It is highly probable that the chemicals are more stable when freshly mixed by the user

Processing chemicals are supplied in concentrated form The usual proportion is one quart of concentrate to one gallon of water It is a simple matter to prepare this mixture in the solution compartment of the processing tank and most users find them satisfactory

Replenishing Chemicals There is a constant loss of volume of processing solution due to evaporation and withdrawal on the surface of the film processed There is also a loss of chemical strength due to oxidation and processing reactions The replenishing solutions are used to keep the tank filled to the proper level and to rejuvenate the processing solution to an effective chemical concentration Replenishing solutions are of a special strength—ordinary strength developing solutions would not serve the same purpose

Chapter XV

Radiographic Technique

Every doctor should be able to produce good foot radiographs if he understands and carries out the basic principles concerning the generation and projection of the roentgen ray. However, it is also necessary to understand the chemistry of the processing procedure and to follow every step of it carefully, because the good work of correct x-ray exposure may be undone by processing faults.

A knowledge of roentgen phenomena should acquaint the doctor with the fundamentals of x-ray generation. However, the application of these fundamentals on a vastly broader scope is necessary for the actual utilization of x-ray energy in terms of projection in order to record foot radiographs. The chapter on roentgen equipment (Chap. XIV) has set forth some of what is expected of x-ray units so they can supply the facilities needed for foot radiography. Consideration will now be given to technique and to the general operation of the x-ray unit.

FACTORS INFLUENCING EXPOSURE OF RADIOGRAPHS

In order to produce a radiograph with any given x-ray generating apparatus, the operator has only four factors to manipulate in making an exposure: milliamperage, kilovoltage, time, and distance. These factors are, however, subservient to current supply and to inherent discrepancies of the equipment. In addition, the emulsion characteristics of the film should be known and the extent of scattered radiation, if any, should be considered. Density and thickness of the part are also of cardinal importance Each of these items will be discussed

Milliamperage. Operation of the x-ray tube is activated by milliamperage which regulates the total output of roentgen radiation The rheostat or filament control is used to vary the milliamperage. A meter calibrated in milliamperes shows the amount. This reading, of course, is only effective when the tube is in operation and transmitting roentgen radiation. The milliamperage control is adjusted to its optimum setting for different levels of kilovoltage because more current is needed to activate the tube at high kilovoltage levels and less is used at low levels A chart for a calibrated x-ray unit will show the proper rheostat settings for the various kilovoltages used This facilitates arriving at the right milliamperage However, in most techniques, milliamperage is not varied as an

exposure factor because the x-ray unit should be operated at the optimum milliamperage for the tube rating

Kilovoltage. The quality of the roentgen output is regulated by the kilovoltage applied to the x-ray tube. High kilovoltage produces a predominance of short x-ray wave lengths. These are more penetrating than the long x-ray wave lengths which are produced by low kilovoltage. The density and thickness of the part to be radiographed are the determining factors in selecting the desired kilovoltage for any given exposure The actual photo-roentgen effect is directly proportional to the mathematical square of the kilovoltage. The lowest kilovoltage that will penetrate the part should be chosen in order to prevent overradiation with a subsequent loss of contrast and detail.

Time of Exposure. The amount of time of exposure is a function of projection rather than x-ray generation At the instant the x-ray tube is set in operation, radiation is available. The operator must decide how much of this radiation is needed to perform the radiograph The quality of the radiation and the amount of radiation intensity remain constant during any desired time of exposure.

A convenient relationship has been established between time of exposure and milliamperage tube current in which the radiographic effect is directly proportional to the time or milliamperage. The expression milliampere-second is commonly used to combine the two factors because they bear the same ratio of photo-roentgen effect.

In spite of this sameness of effect, it is usually not practical to vary either factor at will The capacity of the focal spot size of the tube will place a limit on the amount of milliamperage that may be given off in any exposure. The continuous tube operation rate will be the limiting factor regarding time After the proper penetrating factor of kilovoltage has been selected, time becomes the most feasible exposure factor to vary, in self-rectified units

Distance. The distance involved in the exposure of a radiograph is that from the tube anode focal spot to the x-ray film. Consequently, the tube anode-film distance must be established for every exposure. The greater the distance the roentgen radiation is required to traverse, the more attenuation occurs. This loss is in direct proportion to the square of the distance.

The optimum tube anode-film distance should be selected in proportion to the focal spot size of the tube The finer the focal spot, the shorter the allowable distance. A 24-in distance is convenient in dorso-plantar foot projections because the tube head is below the abdomen level and may consequently be brought into accurate alignment.

Density and Thickness of the Part. In most instances, the foot presents a very large volume of bone in proportion to the amount of soft tissue Radiographic exposure factors may be consistently uniform under these circumstances of density. However, occasionally a foot may be extremely fatty, edematous, or muscular. This will add to the exposure needed The same is true under certain special circumstances; for example, when the foot is encased in a plaster of Paris

cast or any other dressing that cannot be removed. Of course, radiographs of the foot in the shoe also require more exposure.

The size of the foot is a very satisfactory guide for thickness of the part in appraising exposure factors. A technique for measuring the thickness of the part would be difficult to achieve due to irregularities in foot shapes. The average foot sizes are classed as follows:

Small: The foot of a child or of a very small woman.

Medium: The foot of an average woman or of a young man.

Large: The foot of a heavy woman or of a man.

This consideration applies to radiographic exposures of the entire foot. When specific areas of the foot are under inspection, the size of the entire foot is used as a guide for the kilovoltage. The time is then altered in proportion to the thickness of the area being radiographed. This applies to various views of the foot and to single toe work.

Scattered Radiation. As the roentgen ray interacts with the tissue, the incident beam continues through the tissue in a straight line, although it is diminished in intensity due to absorption. At the same time, energy of the same character as x-ray radiation is developed in the tissue and is extended as scattered radiation in a non-specific pattern. This scattered radiation, although of low photo-roentgen intensity, reaches the film and may cloud it with a fog-like density if it is of sufficient proportion. Fortunately, radiographs of the foot do not create appreciable scattering, as do radiographs of the knee, hip, and pelvis, which always present this problem. Devices such as radiographic cones, grids, and diaphragms help prevent undesirable film results for heavy parts but are not needed for the foot.

Characteristics of the Film. The sensitive emulsion of the film may vary in its chemical composition and thereby produce different degrees of contrast together with other film qualities. The doctor must be familiar with the results obtained from different film types and use the type best suited to the exposure in question.

Current Supply. The most glaring possibility of error in radiographic exposure may occur when the line voltage to the unit does not supply the amount of voltage that the machine requires. Practically all x-ray units are provided with a means for line voltage compensation This should be checked very carefully at the time of installation.

Inherent Discrepancies of the Equipment. Kilovoltage that the unit actually delivers is known as "useful" kilovoltage and varies to a small degree from the supposed kilovoltage due to changes in intratubal resistance. Milliamperage may vary with the wave form of the generator However, for all practical purposes, these minor discrepancies are minimized by the latitude of exposure that prevails in radiography. A faulty timer is another possible cause of seemingly unexplicable poor radiography.

Latitude of Exposure. The percentage of error in exposure that may occur is often referred to as latitude of exposure. When the latitude of exposure is exceeded, a sub-par radiograph results However, the radiograph may still be of diagnostic value.

FACTORS TO VARY IN ROENTGEN EXPOSURE

Kilovoltage: Vary kilovoltage in keeping with the size of the foot.

Small (foot of a child or very small woman)—45 Kv. P.

Medium (foot of an average woman or small man)—55 Kv. P.

Large (foot of a heavy woman or of a man)—65 Kv. P.

Kv. P. refers to kilovoltage at peak operation from the secondary of the high voltage transformer and is approximately the useful kilovoltage.

Time. Vary the time of exposure in accordance with the thickness of the part in each radiographic view.

ALTERATION OF ESTABLISHED EXPOSURE FACTORS

Occasionally a technique of known exposure factors that is being used may not give completely desirable results. Contrast may be poor. Too long an exposure time is used which makes immobilization difficult Perhaps the tube is being operated at capacity milliamperage when a conserving lower rate could be used

It is not usually advisable to alter a technique that is supplied by the manufacturer specifically for any given x-ray unit unless this technique is found grossly deficient, because the manufacturer has no doubt developed an exposure technique that is in harmony with the capacity of the equipment However, when it is desirable to change a known technique, the following list of mathematical formulae for alterations may be applied.

Milliamperage–Time Relationship. $Ma_1 \times T_1 \cdot\cdot Ma_2 \times T_2$
Time–Distance Relationship. $T_1/T_2 \,. D_1^2/D_2^2$
Milliamperage–Distance Relationship $Ma_1/Ma_2 \cdot D_1^2/D_2^2$

Kilovoltage–Time Relationship. A change of 10 Kv. P. will require a 50 per cent change in time to obtain the same radiographic density. The only change will be in contrast For example, a two second exposure at 65 Kv. P, a four second exposure at 55 Kv P., and a six second exposure at 45 Kv. P should all produce radiographs of the same density but altered in contrast

Essential Factor Equation. The relationship of all the factors concerned in producing a radiograph may be expressed by a single equation.

Photographic Effect $.(Ma \times T \times (Kv)^2)/D^2$

This formula is used mainly to compensate for the inadequacies of a poor radiograph By noting the exposure factors during a radiograph of the foot, we can compute the numerical value of the photographic effect. Should this radiograph lack the desired density, an estimate of the percentage of deficiency could be made and computed numerically This figure could then be added to the numerical value of Photographic Effect (PE) to get the corrected value of PE The next step would be to substitute the corrected PE value in the formula and resubstitute all of the original exposure factors except the time value. Solving the formula would then give the change necessary to produce the desired photographic effect.

Since it is very impractical to expect accurate results from a chart of exposure factors because of varying voltage conditions and other factors, it is

TABLE 3

Trial Chart of Exposure for Foot Radiographs in Which Kilovoltage Is the Variable Factor in Proportion to Thickness of the Part

Cm	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Kv.	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65

Distance: 24 inch tube anode-film.
Milliamperage: 10 Ma.
Time of exposure: 3 sec.
No-screen film.
Potent processing solutions.
Time and temperature processing.

TABLE 4

Trial Chart of Exposure Factors for Foot Radiographs in Which Kilovoltage Is Varied in Proportion to the General Foot Size and Time Is Varied According to Thickness of Part

45 Kv. P.—Low Range Child's Foot		55 Kv P.—Medium Range Average Woman or Small Man		65 Kv P.—High Range Large, Fleshy, or Swollen	
Thickness	Time	Thickness	Time	Thickness	Time
cm	*sec*	*cm.*	*sec*	*cm*	*sec*
1	1	6	2	11	2
2	1¾	7	2¼	12	2¼
3	2½	8	2½	13	2½
4	2¾	9	2¾	14	2¾
5	3	10	3	15	3

Distance: 24 inch tube anode-film.
Milliamperage: 10 Ma.
No-screen film
Potent processing solutions
Time and temperature processing.

TABLE 5

Trial Chart of Exposure Factors for Foot Radiographs in Which Kilovoltage Is Varied in Proportion to the General Foot Size and Time is Varied According to the Radiographic Projection

Radiographic Projection	Child's Foot (45 Kv.)	Average Woman's or Small Man's Foot (55 Kv.)	Large Foot, Fleshy Foot, Swollen Foot (65 Kv.)
	sec	*sec*	*sec*
Lateral foot.	3	2½	2½
Dorso-plantar foot	2¾	2	2
Postero-plantar calcaneus	2¾	2	2
Lateral digital	½	1	½
Antero-posterior ankle	3	3	2¼
Lateral ankle	3	3	2¼
Oblique ankle	3	3	2¼
Oblique foot	2¾	2	2
Axial sesamoid	2¾	2	2
Dorso-medial foot	2½	1½	1½
Plantar-lateral foot	2½	1½	1½
Plantar-medial foot	2½	1½	1½
Functional first metatarso-phalangeal	2½	2½	2½

Distance: 24 inch tube anode-film
Milliamperage. 10 Ma
No-screen film.
Potent processing solutions.
Time and temperature processing.

suggested that trial exposures be made and any needed alterations either plus or minus to the time factors be recorded on the chart.

STEPS IN MAKING AN X-RAY EXPOSURE

(1) Turn on the line current switch
(2) Set the autotransformer-kilovoltage control for the proper value
(3) Set the rheostat filament control-millamperage control for the proper value.
(4) Adjust the tube at the proper tube anode-to-film distance
(5) Place the loaded film-holder in position on the examining stand
(6) Place the foot in position on the examining stand
(7) Apply the identification marker and the left and right marker.
(8) Center the x-ray focal spot over the part
(9) Direct the central ray from the proper angle
(10) Set the timer for the proper time value
(11) Immobilize the foot
(12) Institute the exposure

RADIOGRAPHIC PROCESSING PROCEDURES

Aside from the image produced by the x-ray on a fluorescent screen, we would find the x-ray rather valueless unless we could utilize the photochemical effect of the ray. Since chemistry plays such an important part in the development of a radiograph, we shall now consider the chemical make-up of the film, processing solutions, and processing reactions.

Chemistry of X-ray Film An x-ray film consists of a sheet of cellulose acetate base that has been coated with a gelatinous colloid of silver bromide. Both sides of the film are coated with the emulsion so that twice as much photographic effect may be recorded during exposure Various types of emulsions create various degrees of sensitivity which require different processing procedures as well as different exposure techniques

The first chemical reaction that takes place in the production of a radiograph is the formation of a "latent image" When the x-ray radiation strikes the silver bromide emulsion, a partial decomposition of the silver bromide to metallic silver takes place. This reaction is of an intrinsic nature and cannot be visualized if the film is examined; thus, we refer to the result as the "latent image" Further chemical treatment is necessary to convert the latent image into a visible radiograph

Process of Development The latent image consists of those portions of the silver bromide emulsion of the film that have become partially decomposed In order to bring out the effect of the ray upon the emulsion, a treatment commonly known as development is applied to the film Development has the effect of further reducing the latent image to metallic silver and this registers on the radiograph as a visible blackness

Development Chemicals (Developer) The following is a list of the chemicals used in the process of development and the specific action of each:

Rhodol and Hydroquinone. reducer.
Sodium sulfite: preservative.
Sodium carbonate: accelerator
Potassium bromide: fog reducer

Process of Fixation. To remove the unexposed grains of silver bromide from the film after it has been reduced by the development process, another chemical process is used. This is known as fixation and clears the film of the excess silver bromide.

Fixation Chemicals (Fixer). The following chemical substances are used in the fixing process:

Potassium alum· film hardener.
Organic acids: neutralizer.
Hypo (Sodium thiosulfate): solvent for undeveloped grains of silver bromide.
Sodium sulfite: preservative.
Buffer salt: sludging preventive.

Washing the Film. The process of washing all residual chemicals and by-products of processing from the film is as important as the chemical reactions used in processing the radiograph. The film must be placed in running water to insure a complete cleansing. Otherwise, the chemicals will remain on the surface of the film and will create discoloration of the radiograph and other undesirable effects.

Drying the Film. Following the complete washing of the film, it is hung up to dry. This process depends to a large extent on the relative humidity of the atmosphere and the circulation of the air, unless some special drying facilities are available.

Regulation of Development Time by Temperature of the Developer. Processing procedures have become so standardized that mastery of the art can be accomplished by anyone in a short time. Scrupulous attention to small details is the secret of good processing work

The biggest contribution to standardized processing procedures is the system of regulating the time of development by the temperature of the developing solution All of the film companies provide a graphic chart showing the ratio between time and temperature for their brands of film. Likewise, the various companies that make processing chemicals provide similar charts. It is best to follow the chart for the particular chemical There are, however, some general rules that should be kept in mind:

(a) The warmer the solution, the shorter the time of development.
(b) The colder the solution, the longer the time of development.
(c) Films should not be examined until processing is completed.
(d) There is no reliable way to compensate for a poor exposure during the original processing procedure

STEPS IN THE PROCESSING PROCEDURE

(1) The temperature of the developer is taken with the thermometer and the time for development is determined by consulting the time and temperature chart.
(2) The "safe light" is turned on General illumination is turned off
(3) The film is removed from the film-holder and the black paper covering it is discarded.
(4) A suitable size film-hanger is selected and the film is clipped tautly on the hanger. Clip the two bottom clips first, then draw the top clips into place and clip.

(5) The loaded film-hanger is immersed in the developing solution and agitated by raising and lowering to remove air bubbles Then it is immediately hung on the shelf in the developing solution
(6) The timer is immediately set for the proper time of development
(7) The empty film-holder is reloaded and replaced in the storage compartment.
(8) When the alarm signal indicates completion of the development period, the film is removed from the developer and dipped up and down for 15 seconds in the water compartment to remove excess developing chemicals Then it is placed in the fixing solution for at least 10 minutes Preferably, the film should remain in the fixing solution for twice the development time
(9) At the alarm signal indicating completion of the fixation period, the film may be examined under white light
(10) The film is next placed in the water-wash compartment to be washed in running water for 20 minutes
(11) After it has been thoroughly washed, the film is hung up to dry

SUGGESTIONS FOR THE PROCESSING DEPARTMENT

Refer to the chapter, "Roentgen Equipment," (chap. XIV) and study all of the details concerning the processing department

Renewing Developing Solution. Developing solution becomes depleted because of the following. loss of chemical strength through film reaction, oxidation by light and air, evaporation resulting from its volatility, and attrition, because each film carries a fraction of an ounce of the solution on its surface as it leaves the developer It is a good policy to renew the developer before it loses its chemical strength, because weak developer causes a loss of definition and other undesirable film effects.

A simple guide to follow in renewing the developing solution is to purchase a gallon of developer replenisher for each five gallons of developer. Add enough replenisher solution to keep the developing solution up to top level in the tank at all times When the gallon of replenisher is depleted, drain the tank, clean it, and replenish all the solutions

Renewing Fixing Solutions The level of the fixing solution seems to remain constant regardless of the number of films processed, because the films that enter this compartment add their surface capacity of wash-water to the content Another factor contributing to maintenance of the same level is the lack of evaporation of these chemicals due to a lower volatility. In spite of the constant level of solution it becomes weak as a result of the dilution with water and the chemical reaction with the film.

The simplest guide for replenishing fixing solution is to make the change at the same time the developer is renewed

Cleaning Processing Tanks A stiff wire brush of the type used by painters is helpful in removing the rim of concentrated chemicals that sometimes forms at the top of the solution tanks Warm water should be used in cleaning the tanks.

Maintaining Tolerable Temperatures of Processing Solutions Temperature conduction through the walls of the tanks from the over-flow water is the common way of maintaining tolerable temperatures (60 to 75 degrees). If hot water is used to raise the temperature of the solution, caution must be

exercised to return the over-flow water to the proper temperature. Otherwise, films in process will be spoiled by both reticulation and softening of the film emulsion.

Dr Richard Oestreich has conceived a method whereby a rack of tubes may be filled with cracked ice and lowered into the developing solution compartment to cool over-warm solution rapidly. This method is very effective.

Reduction of Over-developed or Over-exposed Film. When the original processing of a film produces a film that is blackened by over-development or over-exposure, it is possible to reclaim the radiograph with some degree of success by reducing the excess through a special process known as reducing. However, this is only resorted to when it is impossible to re-expose the case.

Two solutions are used.

(1) Potassium ferricyanide	1 oz
Water q s	16 oz.
(2) Hyposulfite of soda	1 oz
Water q s	16 oz.

The film is immersed in solution No. 2. Enough of solution No. 1 is added to clear the excessive blackness by reduction. This is done by continually rocking the film back and forth in the tray containing the solutions. The film should be inspected from time to time. When it is sufficiently reduced, the film is clipped in a film-hanger, washed for 20 minutes, and then hung up to dry.

Intensification of Light Radiographs. Some degree of success in intensifying light radiographs may be achieved by the following process. The radiograph is first bleached white with a solution composed of:

Potassium bromide	22 50	gm.
Mercuric chloride	22 50	gm
Water q s	1000	cc

The film is then blackened with a 10 per cent solution of sodium sulfite. The intensified negative is fixed in hypo for two minutes and then washed thoroughly.

Routine Precautions to be Observed. Observance of the following precautions will prevent many annoyances during processing.

(1) Do not overcrowd the processing solution compartments If too many films are put in at one time, they are liable to rub against each other and cause spots on the films.

(2) Be careful not to scratch the films with the metal film-hangers. Wet film emulsion is soft and easily scratched

(3) Do not drip fixing solution on work areas or the floor The solution will cause white spots

(4) Never handle film with dirty or oily hands.

(5) Do not let the fingers dip into the processing solutions when adjusting film-hanger spacing The solution on the fingers might be conveyed to other films and spoil them

THE USE OF X-RAY PAPER

Loading Holders. X-ray paper (Powers X-Ray Paper) may be used in ordinary cardboard exposure holders. Since it is coated on one side only, the radiographic image will appear on only one side of the paper. X-ray paper should be placed in the exposure holder with the emulsion side toward the tube side of the holder. An easy way to be sure of proper placement is to place the slippery side (the side that will stick to your moist lip) face down in the envelope side of the holder. The flap should then be brought over the x-ray paper and the sides of the envelope folded in place. This will ensure proper light-proofing By loading the exposure holder in this manner, the resulting radiograph will show the feet in the proper position; that is, the left foot will appear on the left side of the paper and the right foot on the right. In addition, the identification will appear in a readable manner when this system is used. If the identification appears backward, the operator knows that the holder has not been properly loaded

Exposure. When used in cardboard holders, x-ray paper requires more exposure than either regular x-ray film or no-screen film. The recommended exposure factors are as follows.

Dorso-plantar and Lateral Views

Medium size foot (average woman's): 55 Kv. P., 10 Ma., 24 in., 6 sec.
Small foot (child's): Decrease time 3 sec. or reduce Kv. P. by 10
Large foot (large man's, fleshy, or swollen). Increase time 3 sec or Kv P by 10.
Foot in shoe: Add 1 sec to time.

A few trial exposures should determine the combination of exposure factors required to produce the best results with any particular machine

Safe Lights. The same safe lights should be used with x-ray paper as with regular x-ray film. Be sure the processing room is light-proof. X-ray paper is sensitive to both daylight and incandescent light

Hangers. It is not necessary to use special hangers with x-ray paper. By adjusting the tension of the clip springs so that they will not tear the corners when the paper becomes wet, any regular hanger can be used satisfactorily.

Place the two x-ray papers back-to-back (emulsion side out) and mount both on one hanger. This permits processing of more x-ray papers per tank and also helps prevent tearing of the corners

Developing The developing procedure for x-ray paper is similar to that for x-ray film All the standard brands of developer and fixer may be used The developing time recommended by the manufacturer for x-ray film may also be used for x-ray paper with satisfactory results. Generally, x-ray paper requires about two minutes less developing time than the no-screen type of x-ray film. Always use the time and temperature method with x-ray paper.

It is very important to keep the tanks clean and not to use exhausted and discolored solutions, since these will cause the same stains on x-ray paper that they cause on x-ray film To remain permanent, x-ray paper requires the same thorough washing and fixing as x-ray film.

Drying. X-ray paper dries as fast or faster than x-ray film. It may be dried in the same manner as film, in the conventional dryer or in racks. If warm air is introduced, drying time is reduced. X-ray papers should be removed from hangers before they are dry and placed, emulsion back-to-back (never emulsion-to-emulsion), in a pile and a weight placed on top. This procedure will insure perfectly flat radiographs when dry. It also has the advantage of freeing hangers for re-use.

Filing. X-ray paper may be filed without protection in the usual film filing envelopes If the edges are curled a trifle, they may be straightened by rolling them back over the straight edge of a glass cabinet top. No fire-proof vault is necessary since the fire hazard is not greater than with an equal quantity of ordinary paper.

REFERENCES

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Chapter XVI

Evaluation of the Foot Radiograph

It is the responsibility of the physician to be able to appraise a foot radiograph on the basis of a systematic evaluation of the qualities constituting this specialized form of radiography. His first consideration, of course, is what the film portrays diagnostically. He should also be able to evaluate film appearance in regard to such qualities as density, contrast, detail, and image fidelity. Finally, he should be able to relate these film qualities to the technical factors that produced them With this knowledge at hand it is unlikely that the doctor will be satisfied with anything less than fine quality radiography.

EXTRINSIC FACTORS

Certain factors other than the quality of the radiograph must be considered when all the aspects of the examination are evaluated. The visual acuity of the observer is an important factor. The ability to see various gradations of density and to differentiate diagnostic details may vary from individual to individual. One person may favor a dense radiograph of high contrast whereas another may prefer a light radiograph of low contrast Although allowance for differences in visual ability should be made, eccentric ideas concerning radiographic quality should not rank as general criteria.

The quality of the illumination used in the examination of the films must be considered. The film illuminator should provide enough properly diffused light to illuminate the diagnostic areas of maximum density. The color of the light is a matter of personal preference. White and blue-white are most commonly used, although a greenish yellow hue is said to provide the most intense illumination. Rose color, also, is sometimes used A mild, general, room illumination will reduce glare when viewing illuminated radiographs. Extraneous light should be blocked to reduce eyestrain

DIAGNOSTIC QUALITY OF A GOOD FOOT RADIOGRAPH

The diagnostic evidence that can be supplied is the doctor's chief interest in any radiograph. The rule by which the film is judged should be that every element under examination must be clearly and accurately visualized. When the entire foot is under inspection, the following list of questions may be used (the film quality governing that phase of the appearance follows each question).

Appraisal Guide

(1) Is the film that is surrounding the foot sufficiently black or gray to make the diagnostic images stand out clearly? (*Density*)
(2) It there a clear profile of the part visualized? (*Contrast*)
(3) Can the soft tissues be differentiated? (*Contrast*)
(4) Are the structural elements of bone defined? (*Detail*)
(5) Do the bones conform to their natural shape and size? (*Image fidelity*)
(6) Are the joints well-visualized? (*Image fidelity*)
(7) Are the pathologic processes clearly portrayed? (*Detail*)
(8) Are the images sharply defined and free from distortion? (*Image fidelity*)
(9) In the dorso-plantar view of the foot are the toes free from over-exposure when the tarsals are properly exposed? (*Density*)
(10) Is the film free from contamination and defects caused by processing faults or faulty handling?

Radiographs that comply with the diagnostic requirements listed in this appraisal guide are the result of careful following of the principles of production of good foot radiographs (Fig 243).

Connoting Diagnostic Appearances. The doctor interprets black, gray, and white graphic representation into a visualization of tissue elements. Thus, x-ray phenomena penetrate tissue beyond the ability of the eye to inspect and transform it into a graph capable of presenting enough facts concerning tissue elements to be of medical value.

The degree of density observed in normal tissue may be related to the table of absorption coefficients of chosen subjects that was prepared by Barnes and McLachlan.

ABSORPTION COEFFICIENTS

Water $2.506\lambda^3$	Blood $2.61\lambda^3$
Protein. $1.78\lambda^3$	Pus $2.67\lambda^3$
Fat, human $1.135\lambda^3$	Sinew (connective tissue). $2.37\lambda^3$
Muscle, lean. $2.57\lambda^3$	Fatty tissue· $1.37\lambda^3$
Nerves $3.12\lambda^3$	Chemical glassware (jena) $15.05\lambda^3$
Bone cortex $13.24\lambda^3$	Sandstone or quartz $10.25\lambda^3$
Cartilage $2.70\lambda^4$	Iron $107.7\lambda^3$
Fingernail $2.57\lambda^3$	

The relative thickness of the tissue also produces its effect upon the density of the radiograph For example, an area on the film may transmit a whiteness representing roentgen absorption of a thick mass of muscle tissue which in reality is whiter in appearance than the total volume of cortex of a small sesamoid bone. Anatomical experience must be used to evaluate the degree of relativity. It is well to remember.

(1) A tissue or substance of increased density causes a white or clear film appearance
(2) A tissue or substance of decreased density produces a gray film appearance.
(3) The unobstructed x-ray produces a black or an extremely dark gray effect upon the film, depending on the emulsion characteristics of the film used.

FIG 243. A WELL-BALANCED DORSO-PLANTAR FOOT RADIOGRAPH

Roentgen Anatomy of Normal Tissues. Extended study of the radiographic appearance of the intimate structural detail of every foot bone from every radiographic position should be made. The trabecular arrangement should be mastered The proportion of cortex to medullary space and cancellous portions should be carefully evaluated for each age group

The summations of density created by irregular bone shapes must be studied. For example, the doctor should be familiar with the radiographic visualization of the sustentaculi tali of the os calcis as it appears in the lateral view. He should also devote some study to the summations of density that give false impressions of bone density, such as the radiographic appearance of the sesamoid bones of the hallux which are superimposed by the metatarsal bone in the dorsoplantar view Artifacts and lines created by the superimposition of bones and joints in many radiographic views of the foot must be mastered. The normal bone relationships of the foot as a structure should be studied closely.

FILM QUALITY ANALYSIS

Film quality is important because it provides the connecting link between the diagnostic quality of the radiograph and the exposure factors used in producing it. The appraisal guide that was given earlier lists the diagnostic qualities of a good foot radiograph and indicates the film quality that may influence each item of the guide.

Film quality is primarily concerned with the technical appearance of the film. The diagnostic value is secondary. After a discussion of the features of film quality, these qualities will be correlated with exposure factors so that the doctor may understand the practical application There are four features that describe film quality: density, contrast, detail, and image fidelity

Density. When film quality is appraised, density refers to the degree of opaqueness of the exposed areas of the film It is understood that density refers here only to the blackness of the film, and not to the thickness of the substance under examination. Keeping this in mind obviates the confusion that sometimes arises as a result of the use of diagnostic expressions such as, "area of increased density (more dense tissue—whiter area on film)," and "area of decreased density (less dense tissue—darker area on film)."

Total density (complete opaqueness) would be confined to the area of the film

that receives unobstructed radiation. When a portion of the ray is absorbed by soft tissue, a gray area of density is shown on the film When all of the radiation is absorbed by a bone area, the film is clear or devoid of density

A good foot radiograph should exhibit a total film density of moderate opaqueness Film densities of the diagnostic areas of soft tissues should range through a long gradation of gray so that all tissue elements may be sharply differentiated. Bone should appear clear white.

By over-exposing the soft tissue area it is possible to create an area of such density on the film that no visible record of the soft tissue can be visualized. Even small bones may be over-exposed to the same degree

The extremes in film density that are obtainable may be illustrated by the film effect caused by using high speed intensifying screens for extremity work This creates a total density of complete blackness with no gradation of density in the soft tissue The bone appears in chalky white clearness The other extreme is obtained by using film designed for intensifying screen use in a cardboard holder. In this way a total density of grayness is achieved, with soft tissue a shade lighter gray and the bone cortex areas white in appearance.

Contrast. The difference between the total density of a film and an area of complete clearness represents the total contrast of the film Radiographs of the foot should possess sufficient contrast to grade effectively the distinction of density between the various tissue elements and the background density. Bone should be white, flesh gray, and background black

To achieve radiographs with this contrast, careful consideration must be given to many technical details of exposure For instance, over-exposure may "gray out" an area that should appear as clear white Films that have received some stray radiation will not attain proper contrast, because certain areas that should be clear white will be gray because of this prior exposure.

Detail. Film detail is the actual definition of the various tissue elements as demonstrated on the radiograph. The varying degrees of density will shade-in tonal value through differences in contrast

The architecture of bone structure is finely delineated. Every trabecula, fossa, and foramen is recorded The cancellous end of a bone shows a honeycomb pattern because mineralized cell partitions are present Cortical bone, however, is devoid of pattern because it is compact and dense in structure. The medullary canal of a long bone is of decreased density and the resulting radiographic appearance is less opaque than that of the cortical areas.

Summations of density contribute to the patterning of numerous details. The cross-section of a blood vessel is occasionally visualized within soft tissue because the ray meets with sufficient absorption along the sum total of the tubal length of the vessel to record this difference in detail The vessel would not likely be shown if rayed from side-to-side The use of radio-opaque substances emphasizes the margins of a cavity in a similar manner

The image that develops upon the radiograph is basically the product of: a fine roentgen tube, excellent film quality, careful positioning, and absolute immobilization.

Image Fidelity. Radiographic images should reproduce the original object as faithfully as possible. The true shape and size should be maintained and there should be no aberration of detail due to motion.

However, at best, radiographic images cannot reproduce the original object with absolute fidelity because the mathematical inverse square law pertaining to light is at work in radiography. This law states: *The size of the image is geometrically enlarged in proportion to the square of the distance of the object from the film.* Obviously, bones in their normal anatomical position within the tissue cannot be brought into contact with the film; consequently, a certain amount of magnification is always present.

If the x-ray originated from an infinitesimal focal spot, a minimum of penumbra at a minimum distance would be present. However, in each exposure, the image is enlarged a trifle because the crossing rays from the focal spot extend the margins of the object. This distortion is kept at a minimum by using a maximum film-to-tube distance for broad focal spot tubes Fine focal spot tubes may be operated at a minimum film-to-tube distance.

The shape of the object may be perverted if the ray is improperly directed. Any number of bizarre effects may be developed by radiographing a bone from several angles, just as different shadow shapes may be achieved by directing a light source at an object from different angles.

The fidelity of the image may be distorted because of aberration of detail resulting from motion. The familiar blur of fine definition is characteristic of this fault. Motion of the part, of the x-ray tube, or of the film, or of any combination of these will cause this undesirable effect A means of immobilization during exposures is essential.

Inter-play Between Film Qualities. To a large extent film qualities complement each other Contrast depends on differences in film density A film of low contrast is not likely to demonstrate detail to best advantage, because a long scale of grays is likely to rob the film of the sharpness that accentuates detail. It is impossible to maintain film detail if image fidelity is lacking

Inherent Film Characteristics. Desirable film qualities are assured with a minimum manipulation of technical, exposure procedure by the inherent film characteristics that the various film manufacturers have achieved after years of research. The fine grain crystals of the emulsion, their sensitivity to the ray, and the composition of the film-base contribute to the excellent results No-screen film has a capacity for high contrast over a long range and is thus ideally suited to foot radiography.

FACTORS INFLUENCING FILM QUALITY OF FOOT RADIOGRAPHS

The radiograph that falls short of good diagnostic quality by the criteria described in the appraisal guide is deficient in one or more film qualities. The reason for the deficiency may be found by studying the factors that produce the film quality in question All the major factors will be considered in order to give a concise recapitulation for handy reference.

Density

Increased by

Longer exposure time.
Higher milliamperage.
Higher kilovoltage
Shorter distance (tube-to-film).
Prolonged development.
Excessively warm developer.

Decreased by:

Shorter exposure time.
Lower milliamperage.
Lower kilovoltage.
Longer distance (tube-to-film).
Under-development.
Excessively cold developer.

Contrast

Increased by:

Low kilovoltage when no-screen film is used.
No-screen film instead of regular film.
Optimum milliamperage-exposure time.

Decreased by:

High kilovoltage when no-screen film is used.
Regular film in cardboard holder.
Film that has received stray radiation prior to exposure.
Scattered radiation.
Unsafe darkroom light.
Stray light in processing room.
Oxidized, contaminated, or excessively warm solutions.

Detail

Improved by:

Fine focal spot tube.
Optimum distance of tube-to-film in proportion to size of focal spot.
Foot in contact with exposure holder.
Arrest of motion.
No-screen film in cardboard holder.

Decreased by:

Broad focal spot tube.
Too short tube-to-film distance.
Motion.
Processing faults

Image Fidelity

Improved by:

Foot in contact with exposure holder.
Optimum tube-to-film distance.
Fine focal spot tube.
Incident beam centered properly.
Tube aligned at proper angle with foot (observe rules for accurate image production).
Arrest of motion.

Decreased by:

Space between foot and film.
Too short tube-to-film distance.
Broad focal spot tube.
Careless centering of incident beam.
Improper alignment of tube with foot.
Motion.

FILM DEFECTS DUE TO FAULTY PROCESSING ROOM CONDITIONS

The evaluation of foot radiographs would not be complete without a discussion of the defects that occur as a result of faulty darkroom conditions. The embarrassment, inconvenience, and expense of making retakes of important radiographs are reason enough to insist on fault-free work in the processing department. In spite of these valid reasons for careful work, the majority of the mistakes causing failure of radiographic examinations occur during some phase of the processing, rather than during the radiographic exposure itself.

The long list of defects and their causes appearing below is indicative of the many details that must be carefully attended to in the processing department.

Fogged Film (film that has lost detail and contrast due to an overcast-haziness):

Faulty safelight; the result, for example, of too high wattage bulb, unsafe filter, light leaks through screw holes, etc.
Light leaking into the darkroom.
Turning on the white light before the film is properly processed.
Inspecting film before it is properly fixed.
Box of film left open and exposed to light.
Film receiving stray x-ray radiation due to improper protection of film stock.
Radiation directed at the processing room through an unshielded wall while films are being processed.
Over-development which results in a heavy, overall, obscuring density.
Prolonged development in old or exhausted developer which results in a crystallized appearance.
Contaminated developer; for example, fixing solution which has dripped into the developer.
Leaving film in a hot place just prior to development and thus accelerating its development.
Too high a developing temperature.
Out-dated film.

Frosty appearance on surface of film: Insufficient washing period.
Clear spots: Films touching in the developer. Do not crowd the tank.
Milky spots: Films touching in the fixer. Do not crowd the tank.
Dark streaks running from the corners of the film. Chemical stain from dirty film-hanger clips.
A small panel of film undeveloped: Solution below proper level in the tanks so that the film is not covered completely.

Different strata of density: Unequal concentration of solutions either because of dilution with water or need of stirring.

Metallic-like deposits: Oxidation bi-products in the developer. Skim off with a paper towel.

Clear bubble spots: Air bubbles on the surface of the film preventing development. Agitate the film in the solution.

Soft film emulsion: Water too hot during the washing period.

Yellow stain. Excessive development or old developer.

Finger marks: Oily or perspired fingers touching films. Handle film in paper cover until ready to load it in the film hanger.

Black crescent marks: Film bent, with emulsion damage, because of rough handling.

Scratches: Damage to the soft, wet film emulsion by an adjoining clip of a metal hanger. Do not overcrowd the tank. Group the hangers and lower together into the tank Remove in the same manner. Putting them in one at a time risks scratches.

Static crow-feet marks: Recording on the film of the light flash created by static electricity. In a dry atmosphere, wear leather soles to improve natural body grounding.

Oily film surface: Incomplete washing period

Brown film: A film fixed with a weak fixing solution or a film that has been chemically reduced.

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Chapter XVII

Projection Technique in Foot Radiography

Projection technique in foot radiography consists in making an exposure from the proper relationship of the x-ray beam, the foot, and the film, so that the resulting radiograph will demonstrate the condition under examination to best advantage.

Although the x-ray beam is invisible, the doctor must visualize its projection characteristics A discussion of the elements contributing to the projected x-ray beam will clarify some fundamental issues Basic principles of radiographic image formation will be explained and rules given to insure balanced radiographic images.

The posture of the patient during radiographic examination is important and will be given extensive consideration. The position of the foot in relation to the film and x-ray beam will be the subject of a profusely illustrated section that will act as a pictorial guide to x-ray projection technique

PROJECTION CHARACTERISTICS OF THE X-RAY BEAM

The technician performing radiography with knowledge of the projection characteristics of the x-ray beam will produce quality radiography.

Heterogeneous Character of the X-Ray Beam In any given beam of x-ray radiation a variety of wave-lengths is developed. The higher the kilovoltage, the shorter and more penetrating the radiation. The beam of energy carries a total effect upon the radiograph representing the combined intensity of all units of wave length.

Central Ray. Throughout the descriptions of x-ray projection, the term "central ray" is used to designate the most direct radiation from the focal spot of the anode The central ray is the direct incident beam and is the basis of all focusing effort

The x-ray beam emanating from the focal spot of the anode follows a course that might be compared to that of a stream of water from the nozzle of a hose. The center of the stream is aimed at the objective and the peripheral radiation covers the object. The x-ray intensity is practically the same wherever it strikes.

The important issue is the fact that, in forming radiographic images, the central ray follows a straight line to the film, whereas the peripheral rays are di-

vergent and do not create images that are entirely free from geometric aberration. In a dorso-plantar projection of the cuneiform base of the first metatarsal articulation with the cuneiform base of the second metatarsal, the articulation would be nicely visualized if the central ray were projected perpendicular to the joint. If the central ray still remained perpendicular and were moved over the base of the fifth metatarsal bone, divergent rays would reach the articulation at such an obtuse angle that the joint would be obscured.

Line Focus. Practically all x-ray tubes employ an arrangement of filament and anode whereby the focal spot of the tube is increased in efficiency and the x-ray radiation is localized into a more concentrated beam This arrangement insures a better focus with increased detail.

Heel Effect. The angle of projection of the x-ray beam depends on its emanation from the beveled anode focal spot. In line focus tubes this bevel is 20 degrees. Any radiation that develops from the focal spot at the extreme base of the anode bevel, within a range of five degrees, is of such low intensity that it is not effective for radiography. This weak radiation is known as the "heel effect" and should be avoided as a source of available radiation for projection. If ordinary projection precautions are taken this is not a factor of any consequence in foot radiography.

Scope of Radiation. The amount of radiation coverage that can be obtained from a given x-ray tube at a specified distance is known as the scope of radiation. To test for this value, a large film area may be exposed to the x-ray beam and the circular area of black opaqueness that will be noticed after processing represents the scope of radiation for the distance used.

The scope should be known for the x-ray unit in use The technician will then know how much tolerance will be allowed in covering any film size at a given distance.

The circular area of clearness which appears on a corner of a film indicates that the corner was beyond the scope of radiation This effect is frequently referred to as "cone cutting," because the cone applied to the tube absorbs unnecessary, divergent rays and limits the scope of radiation. Even the removal of the cone will not increase the scope on some units, because the actual aperture in the casing that surrounds the x-ray tube limits the size of the scope by absorbing radiation

The scope of radiation may be enlarged by increasing the tube anode-to-film distance because the inverse square law governs the area covered by the radiation, although the intensity decreases with distance.

Effective Tube Alignment. Tube alignment relates to the most useful position of the anode focal spot and to how the tube should be adjusted to keep the x-ray beam at its most efficient projection

Considerable latitude is available in aligning the x-ray tube when line focus is a feature of the projection. Acute angles of the tube that would offer a projection of "heel effect" are to be avoided The "heel effect" might occur if the tube were aligned longitudinal to a part, and then tilted at an acute angle It might also be engendered by the use of an unfamiliar x-ray unit in which the location of the tube is unknown

A general rule is to rotate the tube to achieve the proper position. Do not tilt the tube end-to-end.

Directing the Central Ray: Every x-ray unit should possess a protractor in connection with the adjustment of the tube in order that the central ray may be directed from the appropriate angle. After the tube has been adjusted to the proper angle, the central ray must be carefully directed at the radiographic objective.

The radiographic objective consists of the anatomical structures to be included in the exposure Specifically, a spot is used to designate the best point of entry for the central ray.

Pointing devices of various types are available to aid in procuring faithful alignment of the central ray to the objective and their use insures reliable results. A retracting, steel tape-measure attached to the tube casing is one type. Another consists of a stick as long as the tube anode-to-film distance. It fastens into the cone of the tube and is removed during the exposures. Still another pointing device employs a focused flashlight that sends a beam to the objective.

The experienced technician is usually content to sight the central ray to the objective. This practice brings good results if care is exercised. When the angle is acute from tube to foot, extra precaution is needed. A simple method of aiming the central ray consists of running the tube down the tube-arm until the cone touches the foot centering on the objective, then raising the tube to the proper exposure distance taking care to maintain the same alignment.

The Ortho-x-poser provides a center line and lay-out to assist in guiding the central ray in lateral exposures An inch scale along the film-well is also helpful.

Adjusting the Distance: Radiographic exposure is contingent upon an accurate distance factor. The doctor should decide upon the tube anode-to-film distance that is appropriate for the focal spot size of the tube in use, and then establish a simplified method to arrive at the selected distance with the least possible effort

Most x-ray units are provided with a scale in fractional inches that is mounted on the tube-stand. By simple mathematics, the distance from the film-holder which is placed on the examining stand to the tube-anode which is elevated above the film-holder, may be transposed to the mounted scale. A permanent mark at this point on the scale makes for quick, easy duplication. If the tube-stand does not have a scale, a file mark on the stand after proper measurement assures that the tube-arm may be easily adjusted to the vertical distance

The matter of fixing the distance for lateral exposures is simple when the Ortho-x-poser is in use. The film-well is exactly 20 inches from the front of the Ortho-x-poser Add to this the extra distance to the tube anode and align the tube for horizontal exposure and mark the cone where it meets the end of the Ortho-x-poser at the proper exposure distance Subsequent exposures should follow this distance guide.

The cone may be altered to fit the end of the Ortho-x-poser at a 24 in distance ½ in. above the weight-bearing plane for accurate lateral projections (Fig 244). Cut out a section of the cone ½ in. below the center line and perpendicular to the long axis of the cone. Cover the sharp edge with moleskin so that it will not

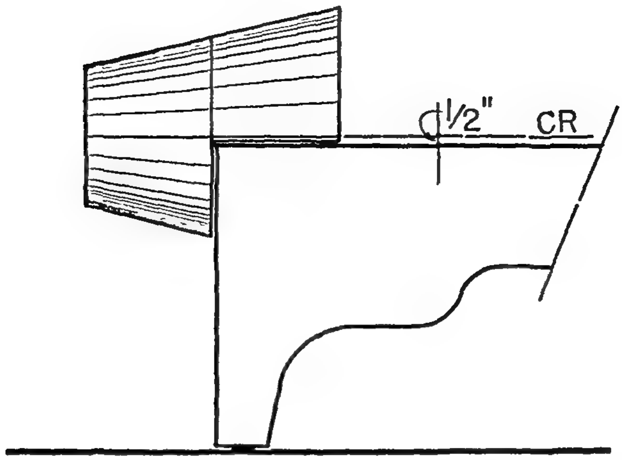


FIG 244. RADIOGRAPHIC CONE ALTERED TO FACILITATE LATERAL FOOT PROJECTIONS (ENLARGED DIAGRAM). The central ray follows a plane ½ in above the weight-supporting plane.

scratch the top of the Ortho-x-poser as it is pressed into position. This simple alteration speeds up lateral projection technique and insures accurate and standardized tube position. The loss of cone effectiveness is minimal and may be ignored.

When the exposure is made at an acute angle, the distances must be individually measured. The standard measure marks can only apply to vertical and horizontal distances. When the central ray follows an acute angle, the tube is lowered but turned on an arc away from the objective to gain the proper exposure distance. A straight rod of the proper length from tube center to the film may be used to check the distance and direct the ray.

BASIC PRINCIPLES OF RADIOGRAPHIC IMAGE FORMATION

The source of the x-ray, the distance involved, plane of exposure, shape of the object, and placement of the object in relation to the film are basic factors contributing to the formation of radiographic images

It should be the object of radiographic examination to produce images that are as faithful to the shape and size of the original as possible. Bones are separated from contact with the film by soft tissue and the film-holder. It is, therefore, impossible to create precise reproduction because of the magnification factor created by the inverse square law. For all practical purposes bones may be reproduced to a size and shape that are faithful.

Source of the X-ray: The sharpness of definition of the image depends on a fine focal spot source of the x-ray beam from the tube anode. A broad focal spot originates rays that extend from several points of source, thereby creating less sharp definition

A special tube modification, a rotating anode, increases the capacity of the x-ray tube while utilizing an exceptionally fine focal spot This type of apparatus is costly compared to stationary anode tubes. A novel radiograph in which the image is greatly magnified can be created with a fine focal spot rotating

anode tube. The technique is to increase the distance between the part and the film. This method is not feasible with a stationary anode tube.

Distance Factors. The inverse square law that governs radiographic images involves three distance relationships. The distance from the anode to the film should be as great as the focal spot size of the tube indicates it to be possible. The greater the distance, the more effective the central ray value in sharp image formation. The closer the object to the film, the less chance for magnification of the image with consequent loss of definition and fidelity. The source-to-object distance is automatically regulated when the ray meets the surface, provided the object is in contact with the film-holder. Any waiver of these relationships will result in distortion.

In any radiographic examination, bones on the side of the foot farthest from the film will be visualized larger than true size, whereas the bones on the side of the foot closer to the film will be of more accurate bone size. The axiom, "the part closer to the film renders the best detail" is technically true; however, on observation it is difficult to distinguish in any given radiograph which side of the foot was in contact with the film during exposure. If two exposures from different sides are provided, it is an easy matter to measure a given bone such as the cuboid since the film showing the larger sized bone represents the side of the foot at the greater distance from the film.

In any lateral view of the entire foot, there is always an overall magnification of foot size due to the divergent rays extending the foot at each end. The parts adjacent to the central ray are most accurate in size (Fig. 340).

Later in this book, a technique in which the entire outline of the dorso-plantar view of the foot is visualized on the radiograph will be described This full-foot view is accurate in respect to foot size because two exposures are used to create the image. In each exposure the central ray is directed in such a manner as to create accurate image size. Furthermore, the point of contact of the flesh is sharply delineated upon the film when the central ray meets it obtusely. This contact outline is more accurate than a pencil contact that would be held away from the film by the thickness of the wood to the lead (Fig 341).

These explanations are made because often a lateral view of the foot is composed on the same film with a full foot radiograph and it is readily noted that the lateral view is larger than the full-foot view The latter is a correct size from the flesh outline of the tip of the great toe to the flesh outline at the back of the heel

Plane of Exposure. The direction of the projected x-ray beam is termed the plane of exposure. It may be horizontal, vertical, or oblique. Oblique planes of exposure embody an angled alignment of the central ray and may be applied to either horizontal or vertical planes of exposure

When the x-ray beam reaches its radiographic objective, its course is described in anatomical terms with the surface of entry named first and the port of exit named last For example: the dorso-plantar ray enters the dorsum and leaves the plantar surface to reach the film

These anatomical descriptions are popularly called radiographic views. They also designate the radiographic projection

Shape of the Object: The radiographic image represents the sum of the densities of an object from any one plane of exposure. The shape of the object plays an important part in the appearance. If the shape of the object were triangular the image would visualize a greater density in the center. If a tubular object were radiographed from end-to-end, a circle of increased density would result. If the tubular object were laid on its side and radiographed, the image would be visualized as an area of increased density on each side, and an area of decreased density in the center, because the volume of the wall of the tube would be greater than that of the top and bottom of the tube.

In relating these abstract forms to bone, it is evident that the same principles prevail. The tubular shaped metatarsal bone visualizes dense cortex at the sides and a less dense medullary portion in the center. Actually, the cortex is of essentially the same thickness all around the shaft. It is the combined volume of the wall of the shaft, rather than the fact that the cavity of the medullary portion of the bone is exposed, that creates the appearance. Practically every radiographic image abounds with similar situations.

Film Placement. It has been repeatedly mentioned that the foot must be as close as possible to the film for accurate results. The film may be placed in either vertical or horizontal position.

The Plane of the Bones Presented for Radiography. In choosing the proper planes of exposure and the angle of projection of the central ray, it is extremely important to take into consideration the plane of the bones presented for radiography. In most instances the surface overlying the foot structure that meets the eye is a reliable guide to follow, however, the true shape of the bone to be radiographed and its anatomical position may be couched deeply in the flesh so that the external surface is a poor guide to its true plane. The doctor must exercise anatomical judgment in such instances to obtain the proper radiographic requirements In the case of the calcaneus, the tendo achilles and ankle make-up present a vertical surface although the calcaneus lies on a severe angle within the tissue

RULES FOR PRODUCING BALANCED RADIOGRAPHIC IMAGES

Rule (1). When the plane of the bones presented for radiography lies parallel to the film-holder, project the central ray directly perpendicular

Application In a dorso-plantar view of the great toe, the surface is parallel with the film-holder The x-ray tube which, when set at 0, aligns the central ray in a vertical plane, should be maintained in this perpendicular alignment and be directed at the objective to produce a balanced radiographic image (Fig. 265).

Rule (2). When the plane of the bone presented for radiography lies on an oblique plane in reference to the film-holder, the central ray should be directed perpendicular to a line that would bisect the surface film-holder angle (Figs. 245–247)

Application. In a dorso-plantar view of the foot, the surface tapers obliquely from the ankle to the base of the toes An observation of this angle from a side view would reveal the degree In the foot of average arch height the angle would be 30 degrees. Half of this would be 15 degrees. The x-ray tube which, when set at 0, aligns the central ray in a vertical plane, should be rotated 15 degrees so


FIG 245 (Left) RADIOGRAPH MADE WITH CENTRAL RAY DIRECTED FROM THE PROPER ANGLE Angle in this case is 15° from vertical in an antero-posterior direction

FIG 246 (Right) RADIOGRAPH OF THE SAME FOOT AS IN FIG 245 Made with central ray at 45° from vertical in an antero-posterior direction Note the elongation of the metatarsal shafts, position of sesamoid bones, and closure of metatarso-phalangeal joints

that the central ray may be directed properly at the objective to produce a balanced radiographic image (Fig. 246).

In practice, the appraisal of the angle presented may be quickly approximated. The pes cavus foot would require a 20 to 25 degree angle of projection The pes planus foot would require a 5 to 10 degree angle of projection.

Rule (3). When it is desired to visualize an articulation between two bones, the central ray should be directed parallel through the articulation. Anatomical judgment governs the direction of the central ray (Fig 271).

FIG 247. RADIOGRAPH OF THE SAME FOOT AS IN FIG. 245–246. Made with central ray at 10° from vertical in a postero-anterior direction. Note shortening of metatarsal shafts, posteriorly located sesamoid bones, and pseudo-fused appearance of tarso-metatarsal joints The metatarso-phalangeal joints are partially closed.

Application. The lateral cuneiform bone articulates with the middle cuneiform bone at an angle of about 35 degrees. The tube is aligned with the length of the foot, and the angle of the central ray is set at 35 degrees so that it may pass perpendicularly through the joint

In these instances the shape of the bones may be perverted, but the joint margins are clearly visualized, and this is the object of the examination.

POSTURE OF THE PATIENT

The posture of the patient during radiographic examination is determined by the type of condition under examination. The natural weight-supporting attitude is most feasible for patho-mechanical conditions. When traumatic or pathologic lesions affect the feet so that the patient is incapable of comfortably sustaining body weight, the recumbent attitude with the patient in repose or seated with the foot in a resting position is best The rare emergency stretcher patient, of necessity, would be radiographed in a supine position.

Weight-supporting Attitude. The natural, weight-supporting posture places the foot structure in the anatomical situation that exists under the stress and strain that bearing body weight creates. The integrity of the foot regulates the degree of structural change visualized Under normal circumstances the full excursion of joints is developed This status is in marked contrast with the structure that is visualized when patho-mechanical problems are present with foot articulations mal-aligned Little value could be attached to radiographs of this type of case if they were performed with the foot relaxed and the patient in recumbent position, because typical mal-alignments would not be present.

The standing attitude has other advantages. The foot is fundamentally aligned

at a right angle with the leg in an upright pose; consequently, radiography in this position contributes to standardization of radiographic views for subsequent exposures. The attitude of standing promotes good foot immobilization without the need of auxiliary devices such as sandbags, restriction bands, etc.

It is a simple matter to change the patient from one radiographic position to another. Positions are achieved by merely facing the patient from left to right and vice versa. Compare this to rolling a patient, especially a corpulent person, on a table from side-to-side.

The efficiency gained with the patient in weight-supporting attitude saves office time, patient inconvenience, and strain upon personnel performing the radiography. Power retakes are needed because of more faithful immobilization. A better foundation for research is established through effective standardization.

When co-existing pathology of bone is present and the patient is able to stand, the erect posture should be used because the pathologic process will be clearly visualized from these radiographs, wherein the part is firmly held close to the film.

Recumbent Attitude. In many instances the patient may be unable to stand because of traumatic lesions or pathologic conditions; consequently, the radiography must be performed with the foot in a resting position. This may be achieved with the patient in a supine attitude lying on a radiographic table, or with the patient seated and the foot resting on the Ortho-x-poser or possibly the foot-rest of the treatment chair.

When radiography is performed with the foot in recumbent attitude, special care should be exercised in directing the central ray so as to duplicate standard position requirements. It must be borne in mind, too, that the anatomical alignment of the foot may be unnatural because of muscle spasms from pain, and that this must be taken into consideration in trying to achieve proper radiographic views; otherwise, a false impression might be gained in the visualization. Unfortunately, many doctors have radiographed the foot upon the foot-rest from the dorso-plantar plane of projection with little consideration to proper angles of exposure. Therefore many foot radiographs performed in this manner demonstrate pseudo-ankylosis of tarsal joints, fore-shortened metatarsal bones with increased girth, and other bizarre appearances that lead to faulty interpretations.

The recumbent attitude is very useful in obtaining views of foot areas that cannot be brought into profile in standard weight-supporting projections. In many special projections the foot may be turned to a favorable position while the patient is seated on a stool beside the Ortho-x-poser.

In cases of trauma, it is sometimes very convenient to transport the patient via the operator's chair, which is very mobile.

RADIOGRAPHIC PROJECTIONS

Each radiographic view will permit visualization of only one anatomical plane at a time. In order to produce a diagnostic series it is necessary for the doctor to know how to direct the x-ray at the foot from a variety of projections.

To gain a three dimensional visualization, two views must be produced, with

the radiographic projections at right angles. The width and length of the navicular bone may be seen in the dorso-plantar view, while the depth of the bone is added in the lateral view. An elevation view is gained of the entire foot from the lateral view, whereas the plan view is obtained in the dorso-plantar view. Although it is highly desirable to produce radiographic views from precise right angles, it is often impossible because of the anatomical position of such bones as the middle cuneiform. In this case a series of views from various angles will add information concerning the bone. In many cases the pathology may be disclosed to good advantage by an oblique view that may distort the bone from the standpoint of true shape. The central ray should be used as a probe to explore until satisfaction is gained.

Standard Projections. Countless x-ray exposures of feet have been made as an aid to diagnosis since the discovery of roentgenography, but, until recently, there has not been any effort to create a truly standardized technique for foot roentgenography. Many of the techniques that have been used in the past have been outmoded by conveniences offered by newer types of x-ray generating equipment and accessories.

The foot, with its many bones and complex articulations, presents many pitfalls for the x-ray technician, because one finds overlapping bone images in almost every x-ray view of the foot. For practical purposes it is well for us to select those projections which will show a majority of the important bones of the foot with as few overlapping shadows as possible. This is especially important in the study of the relationship of a group of bones Once we have become familiar with the outline of the bones as projected by a specific standard projection, we can expect all radiographs taken in that standard projection to conform to the same general pattern Interpretation of the foot radiograph is, therefore, greatly simplified if standard projection technique is used. Often the practitioner desires to follow the course of a condition roentgenographically. By the use of standard projection technique he can make each radiograph of the series an exact duplication of position, thereby being assured of an accurate comparative study. It is very important for the doctor to realize the necessity of perfect positions in serial work. If he is lax in the precision of his series of exposures, he will almost surely have a false interpretation of the case

To perform a standard radiographic projection, there must be a fixed relationship between the foot, the x-ray, and the central ray To simplify these requirements, the Ortho-x-poser provides facilities that insure uniform results. The weight-supporting attitude assures uniformity in the position of the foot in respect to the leg—essentially a right angle—where the recumbent attitude would develop such a variety of relaxed positions of the foot that it would be very difficult to reproduce any radiograph with accuracy A light-proof film-holder is provided to contain the x-ray film This film-holder should be held in a fixed position, thus eliminating distortion due to movement of the film The film-holder should also be fixed in a definite position in relation to the foot so that the film-foot relationship may be re-established at any time The central ray must be accurately related to the film-foot position A centering spot on the foot is chosen, and the central-ray is directed at it from the proper angle of exposure The high fidelity test for a standard position set of radiographs is to superimpose one upon the other, in which case the bone outlines should coincide

precisely. This extreme test is seldom necessary, if ever, in radiography, for the very close approximation produced by ordinary care will be sufficiently accurate for the most discerning eye in the usual diagnostic survey. The object of standardization is to produce similar radiographs so that there may be a uniform basis of technique and interpretation. The change in foot structure that occurs over a period of time precludes positive superimposition of radiographs; however, the standard projection technique readily shows the change that has taken place.

Standard Projections

(1) Lateral foot projection.
(2) Dorso-plantar foot projection.
(3) Postero-plantar calcaneus projection.
(4) Lateral digital projection.
(5) Antero-posterior ankle projection.
(6) Lateral ankle projection.

Special Projections. There are many informative x-ray views that do not lend themselves to standard projection technique because varied angles and positions of the foot may not be easily duplicated. Oblique views of the ankle and foot are examples of this type of position. The series of positions described under this heading are extremely useful and are often added to standard projection radiographs to complete a diagnostic survey.

Special Projections

(1) Oblique foot projection.
(2) Oblique ankle projection.
(3) Axial sesamoid projection.
(4) Dorso-medial foot projection.
(5) Plantar-lateral foot projection.
(6) Plantar-medial foot projection.

Functional Projections. Frequently it is important to radiograph an area where the bones involved are articulated into such a position as to be symptomatic; e.g., hallux rigidus. The foot is flexed at its metatarso-phalangeal articulation until pain occurs. Exposure is instituted at this position while the patient maintains this functional pose. Another example would be radiography of an anesthetized ankle with the foot held in extreme inversion to check the competence of the ligament structures following trauma

Functional Projection:

(1) Functional First Metatarso-phalangeal Projection

Individual Bone Projection. Many times the practitioner desires to demonstrate the condition of an individual bone such as the middle cuneiform. This bone is difficult to portray in clear profile since it is wedge-shaped and closely articulated with adjoining bones. Careful manipulation may bring this bone into position for a plan profile view from a plantar-dorsal exposure. The operator will find that he will be greatly aided in securing trial positions if he will use an anatomical foot skeleton as a guide, placing the skeleton over a white piece of paper and adjusting it until white may be seen around the bone. Duplication of this position with the patient's foot will result in the desired radiographic view.

Figs. 248–286. Basic Projection Technique and Technical Factors

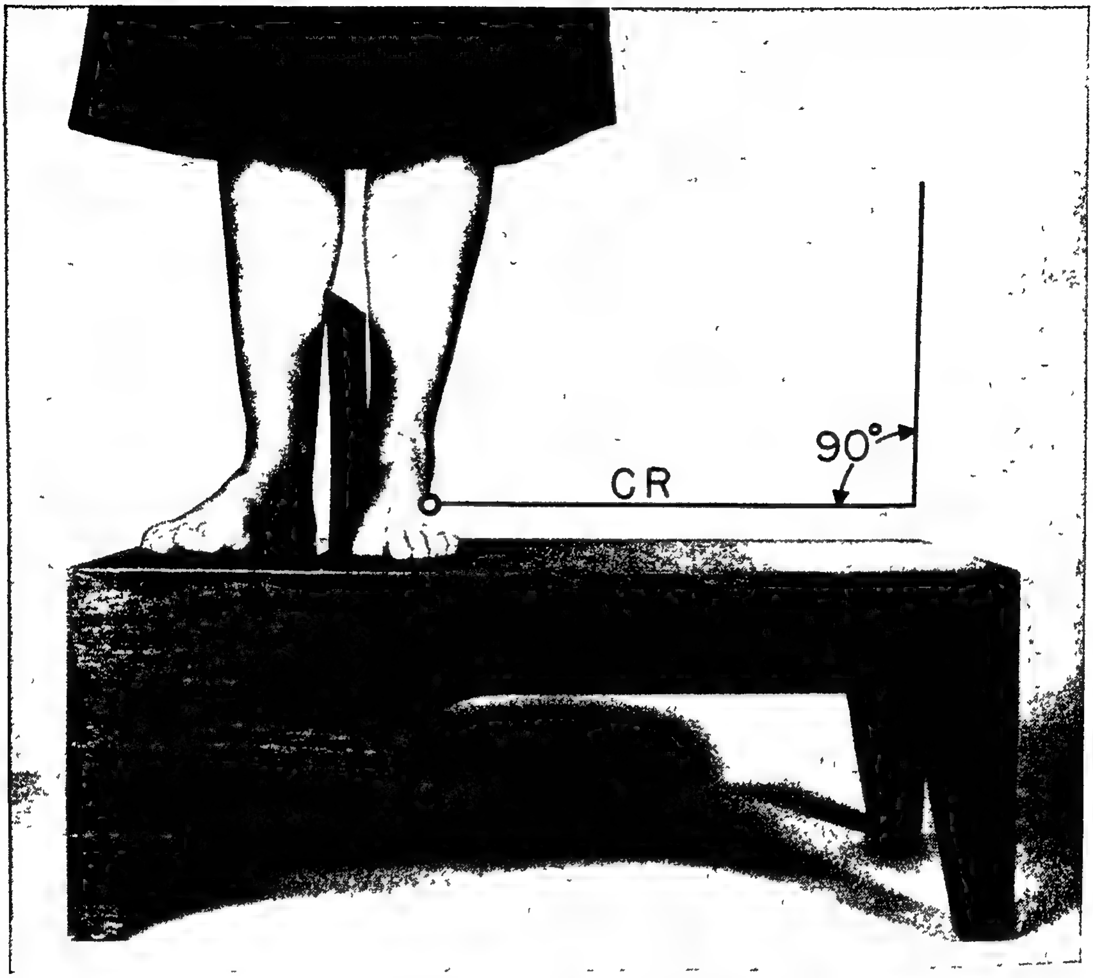


Fig 248 Standard Lateral Foot Projection

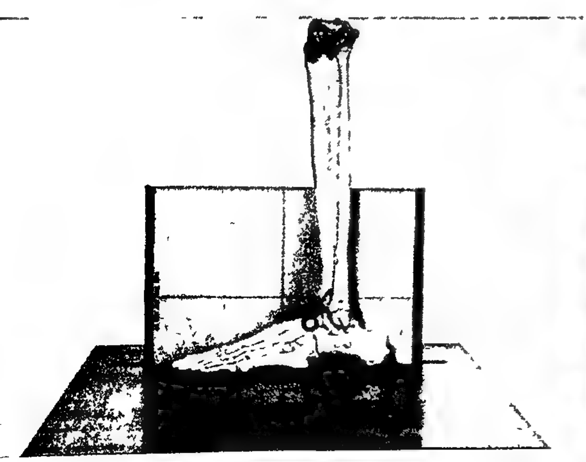


Fig. 249 Centering

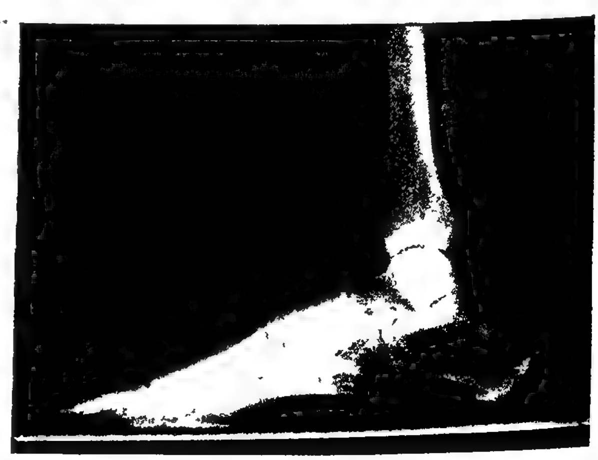


Fig 250 Radiograph

LATERAL FOOT PROJECTION (Figs. 248–250)

Standard Projection:

Film: Secure the film-holder in vertical plane.
Foot: Pose patient with medial malleolus and first metatarso-phalangeal joint of the foot under examination in contact with film-holder. Assist patient to assume natural pose with indifferent foot.
X-Ray: Direct central ray parallel with the top of the Ortho-x-poser at a 90 degree angle from the vertical plane.

Centering:

When the entire foot and lower third of leg is to be included in the radiograph, aim central ray perpendicular to the film at the head of the talus.
When the usual arch study is made, aim the central ray at the lower aspect of the cuboid at a level ½ in. above the Ortho-x-poser. This will insure both accurate relationship of the medial longitudinal arch with the lateral longitudinal arch, and proper sesamoid level.

Radiograph:

Mid-tarsal joint	Navicular	Fifth metatarsal
Sinus tarsi	Medial cuneiform	Lower third of tibia
Calcaneus	Cuboid	Lower third of fibula
Talus	First metatarsal	

TABLE 6

Lateral Foot Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot 45 Kv —3 sec	
Medium foot 55 Kv —2½ sec	
Large foot 65 Kv —2½ sec	
Distance 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing

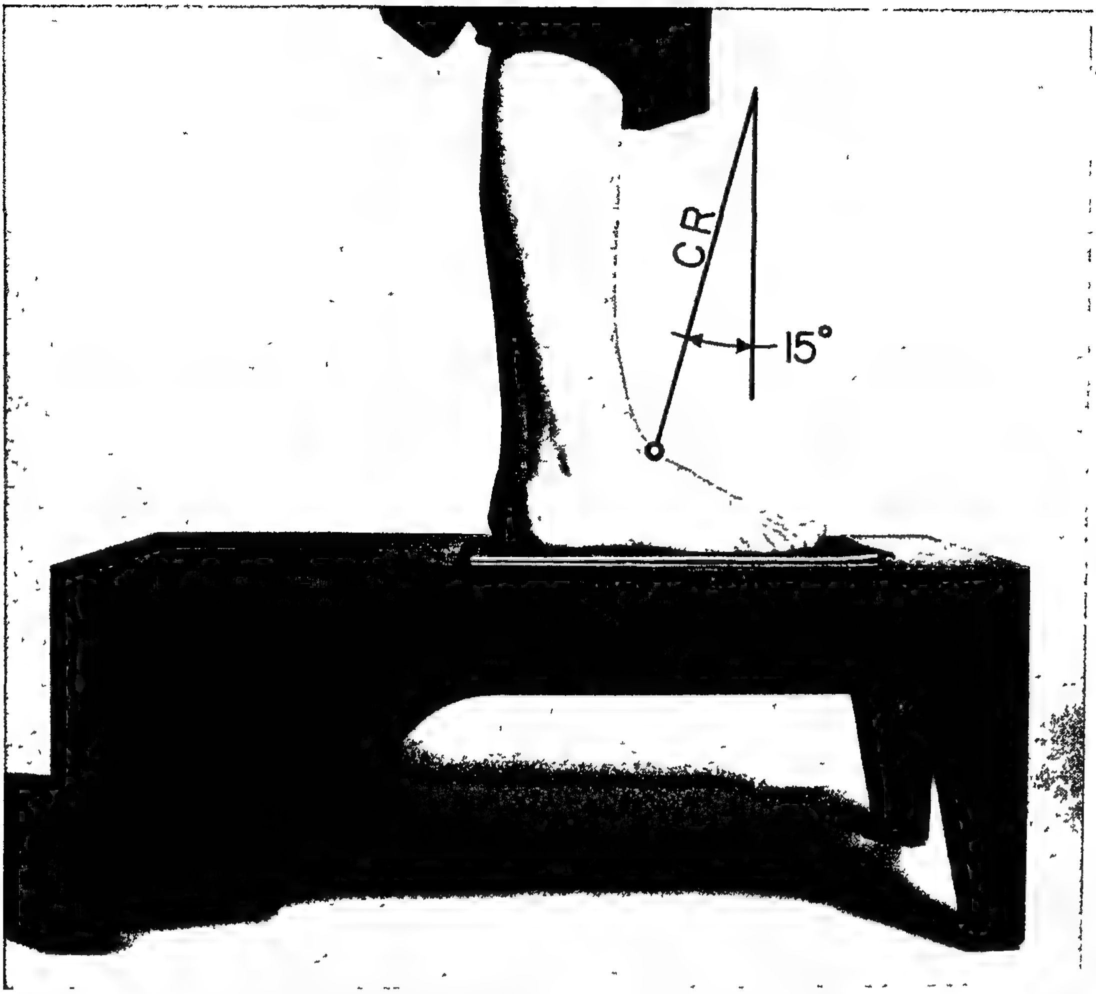


Fig 251 Standard Dorso-plantar Foot Projection

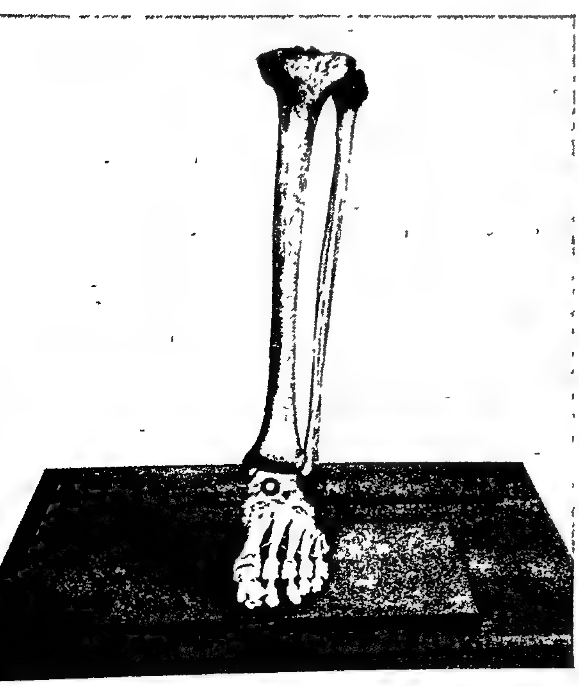


Fig. 252 Centering

Fig. 253 Radiograph

DORSO-PLANTAR FOOT PROJECTION (Figs. 251–253)

Standard Projection:

Film: Place the film-holder on top of the Ortho-x-poser.
Foot: Pose the patient in standing position with foot on the film-holder.
X-Ray: Direct central ray from a 15 degree angle from the vertical plane for average medium height arch foot; 20 degree angle for high arch foot; 10 degree angle for low arch foot.

Centering:

Aim central ray at the head of the talus where the foot meets the ankle at the mid-line of the foot. Be sure tube is aligned so that the ray will follow the longitudinal axis of the foot.

When central ray is centered at ankle and foot junction, the peripheral rays travel a greater distance to the toe region, thereby favoring a better balanced density of the entire radiograph.

Radiograph:

Mid-tarsal joint
Head of talus
Anterior portion of calcaneus
Navicular
Cuboid
Medial cuneiform
Middle cuneiform
All metatarsals
All phalanges
Sesamoids of hallux

TABLE 7
Dorso-plantar Foot Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot 45 Kv —2¾ sec.	
Medium foot 55 Kv.—2 sec	
Large foot 65 Kv.—2 sec	
Distance 24 inches anode-film	
Milliamperage · 10 Ma	

No-screen film—Potent solutions—Time and temperature processing.

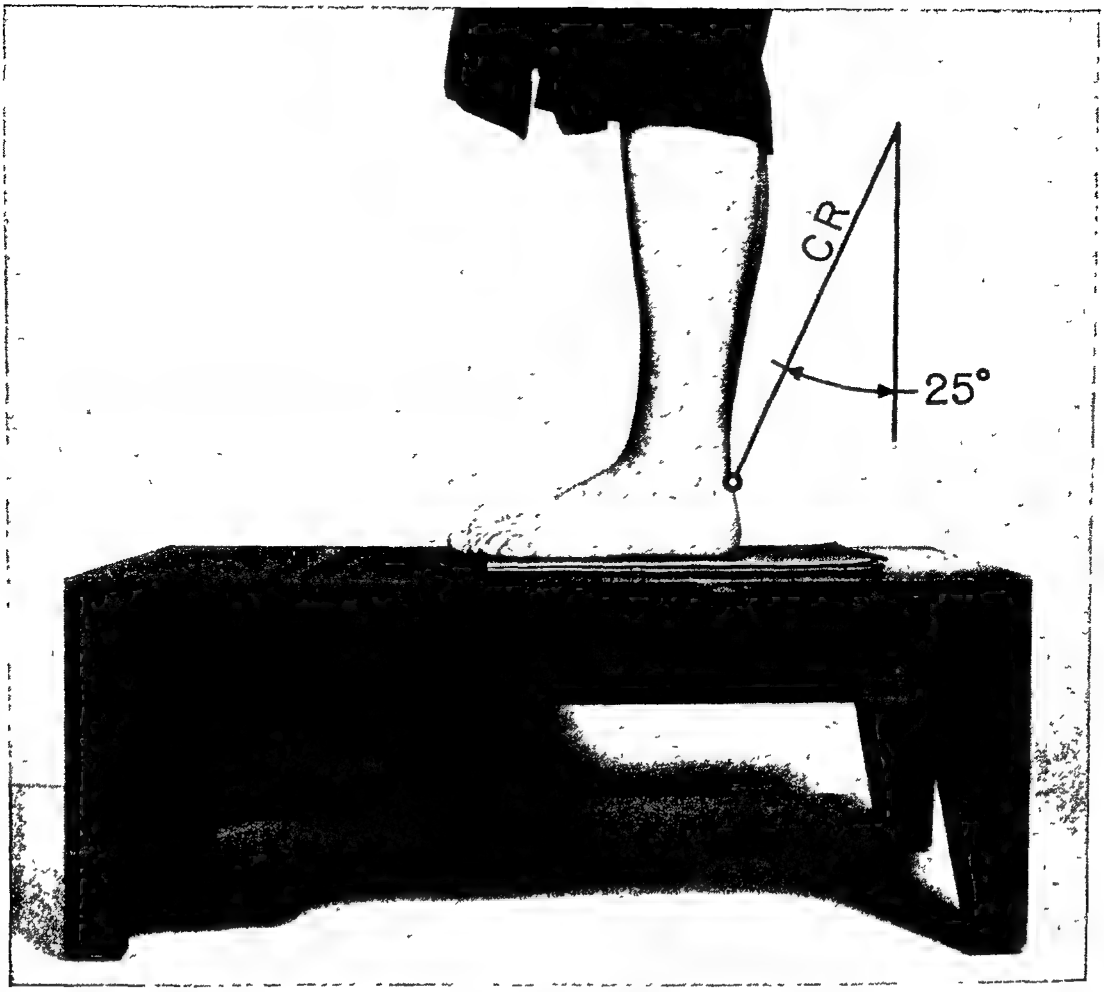


Fig 254 Standard Postero-plantar Calcaneus Projection

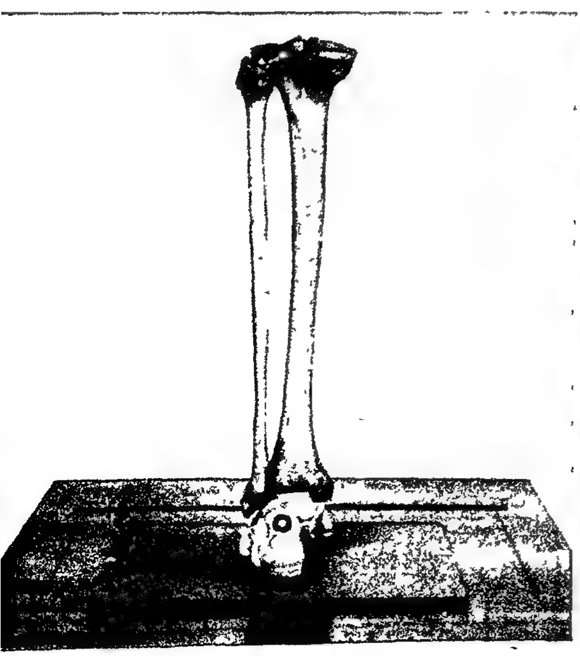


Fig. 255. Centering

Fig 256 Radiograph.

POSTERO-PLANTAR CALCANEUS PROJECTION (Figs. 254–256)

Standard Projection:

Film: Place the film-holder on top of the Ortho-x-poser.
Foot: Pose the patient in standing position with foot on the film-holder. No need to bend knees when 24 in. distance is used.
X-Ray: Direct central ray from a 25 degree angle from the vertical plane.

Centering:

Aim central ray at the achilles tendon at the level of the lateral malleolus. Be sure tube is aligned so that the ray will follow the longitudinal axis of the foot.

Radiograph:

Posterior aspect of the calcaneus in axial profile.

TABLE 8

Postero-plantar Calcaneus Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot. 45 Kv.—2¾ sec.	
Medium foot. 55 Kv.—2 sec	
Large foot 65 Kv.—2 sec	
Distance 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing.

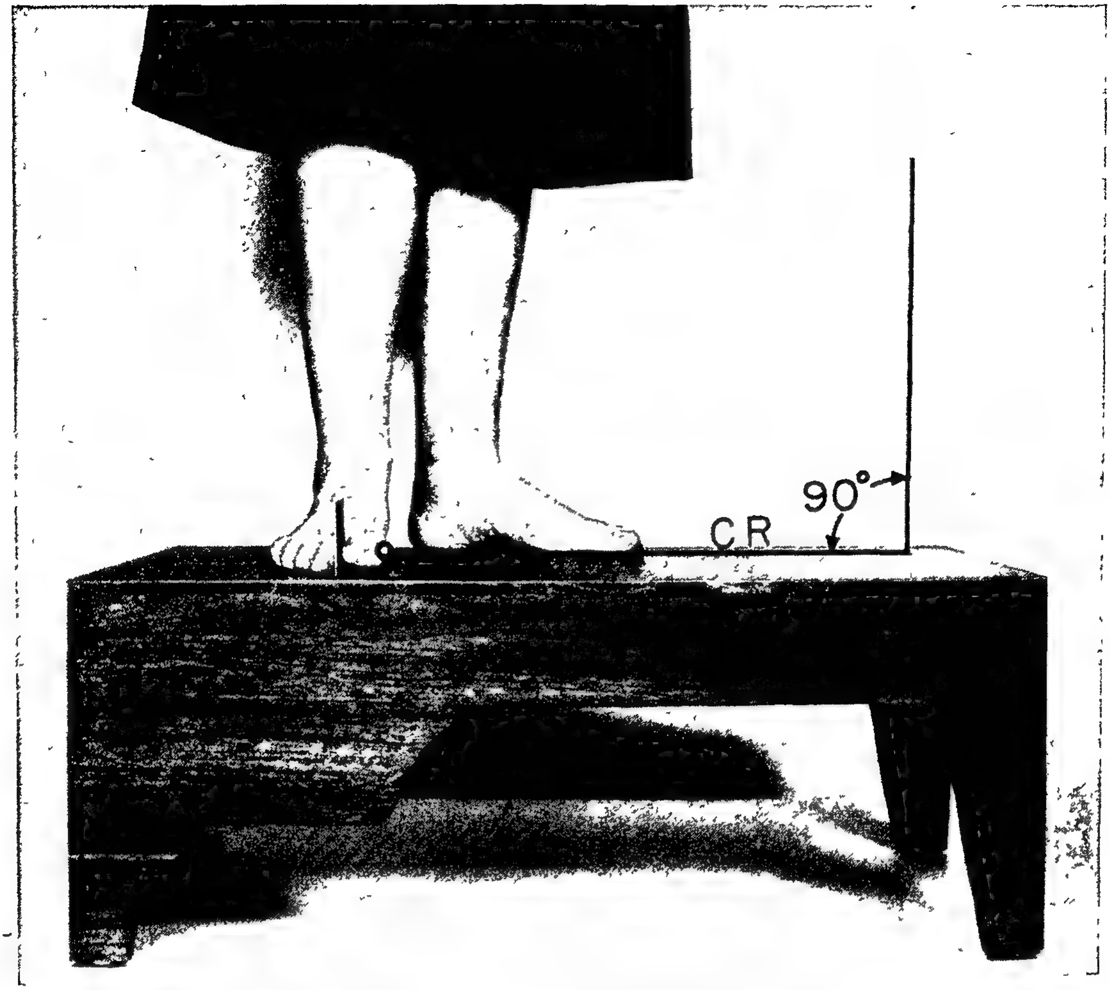


Fig 257. Standard Lateral Digital Projection

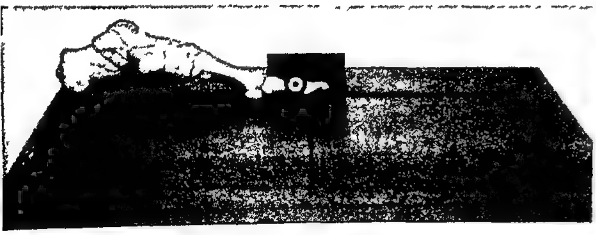


Fig. 258. Centering.

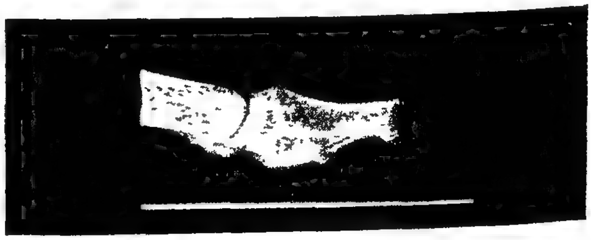


Fig 259 Radiograph

LATERAL DIGITAL PROJECTION (Figs. 257–259)

Standard Projection:

Film: Secure film-holder in vertical plane.
Foot: Place lateral border of great toe next to film-holder by sliding foot forward, spreading toes apart. Patient may stand or sit with foot in resting position.
X-Ray: Direct central ray parallel with the top of the Ortho-x-poser, at a 90 degree angle from the vertical plane.

Centering:

Aim central ray perpendicular to the film at the center of the toe.

Radiograph:

Distal phalanx
Portion of second phalanx

TABLE 9

Lateral Digital Projection

Suggested technical factors	Adjust Chart for Unit in Use
Small toe· 45 Kv.—½ sec	
Medium toe. 55 Kv.—1 sec	
Large toe· 65 Kv —½ sec	
Distance. 24 inches anode-film	
Milliamperage. 10 Ma.	

No-screen film—Potent solutions—Time and temperature processing

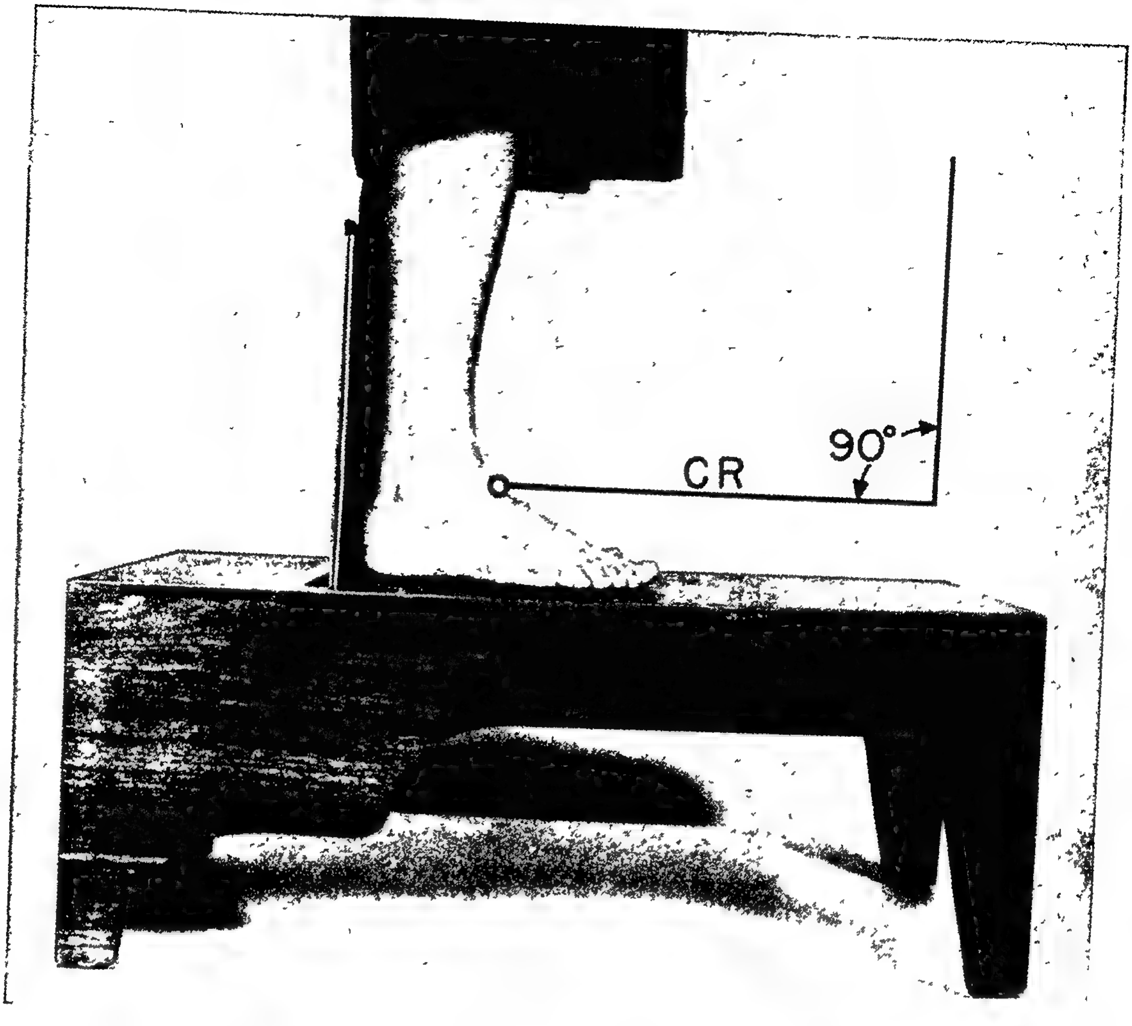


Fig 230 Standard Antero-posterior Ankle Projection

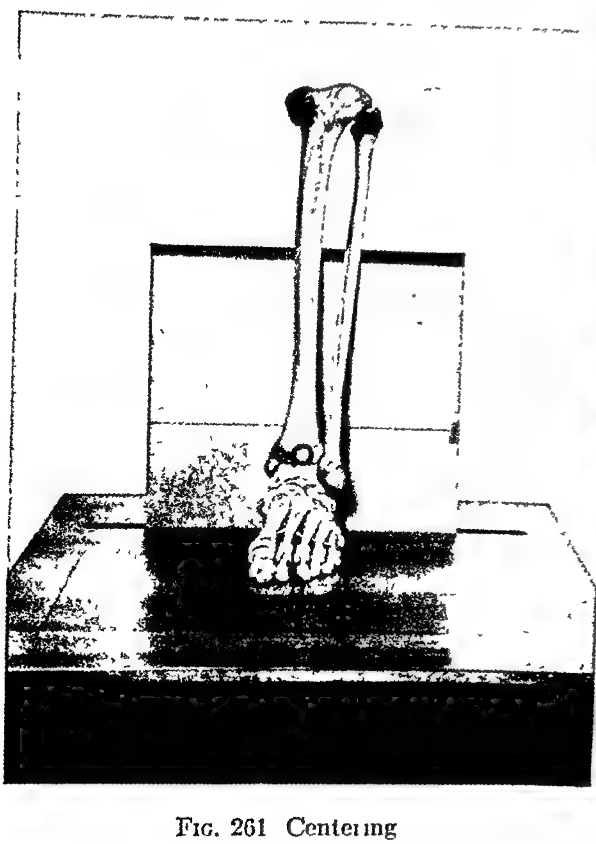


Fig. 261 Centering

Fig 262 Radiograph

ANTERO-POSTERIOR ANKLE PROJECTION (Figs. 260–262)

Standard Projection.

Film: Secure film-holder in vertical plane.
Foot: Pose patient with heel of foot and posterior part of ankle and leg in contact with the film. Set foot perpendicular to the film-holder.
X-Ray: Direct central ray parallel with the top of the Ortho-x-poser, at a 90 degree angle from the vertical plane.

Centering:

Aim central ray perpendicular to the film-holder at the ankle joint.

Radiograph:

Lower portion of fibula
Lower portion of tibia
Superior surface of talus
Tibio-fibular joint
Ankle joint

TABLE 10
Antero-posterior Ankle Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small ankle· 45 Kv —3 sec	
Medium ankle 55 Kv.—3 sec	
Large ankle 65 Kv —2¼ sec	
Distance. 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing.

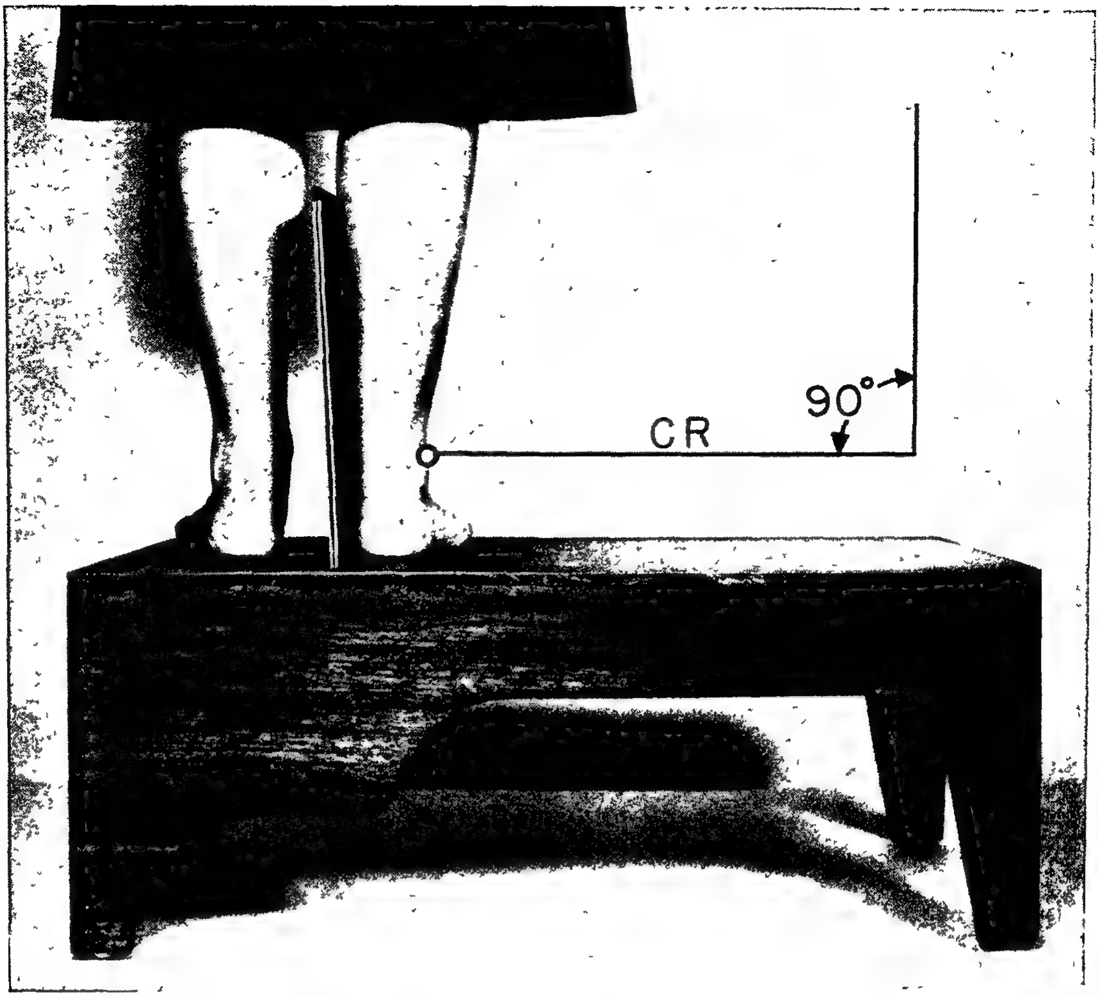


FIG. 263. Standard Lateral Ankle Projection.

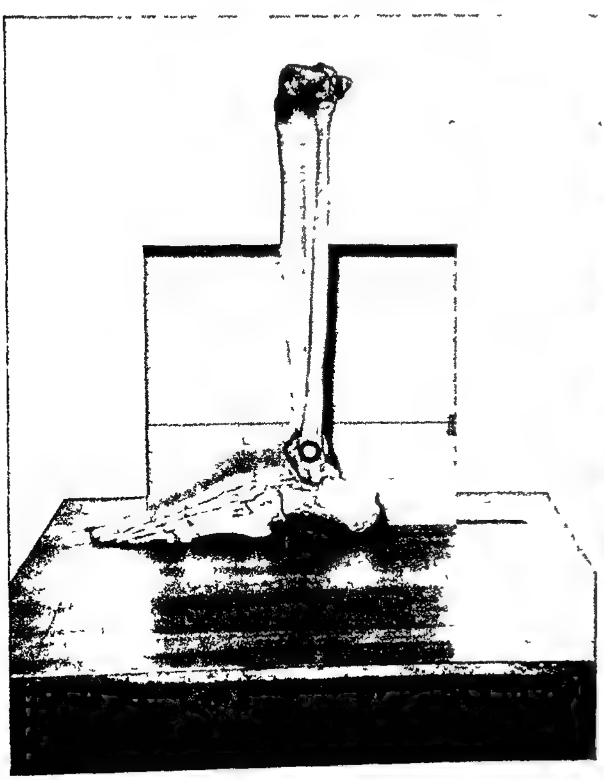


FIG. 264. Centering.

FIG. 265. Radiograph.

LATERAL ANKLE PROJECTION (Figs. 263–265)

Standard Projection:

Film: Secure the film-holder in vertical plane.

Foot: Pose patient in erect position with internal malleolus and first metatarso-phalangeal joint in contact with the film-holder. Approximate this pose if patient is injured.

X-Ray: Direct the ray parallel with the top of the Ortho-x-poser, at a 90 degree angle from the vertical plane.

Centering:

Aim central ray perpendicular to the film at the level of the external malleolus.

Radiograph:

Lower portion of the fibula
Lower portion of tibia
The ankle joint
The sub-talor joint

TABLE 11

Lateral Ankle Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small ankle 45 Kv —3 sec.	
Medium ankle 55 Kv —3 sec	
Large ankle. 65 Kv.—2¼ sec	
Distance 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing.

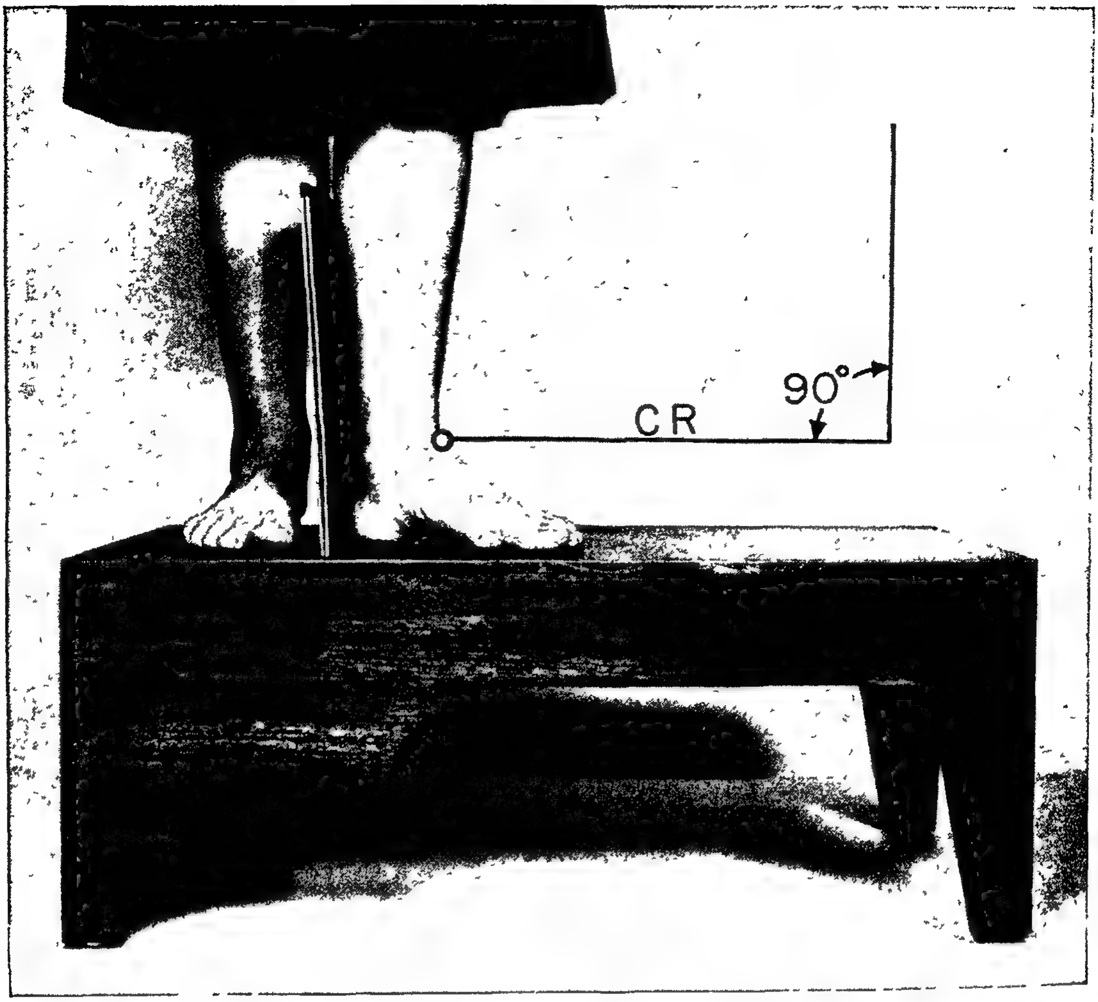


Fig. 266. Special Oblique Ankle Projection

Fig. 267. Centering.

Fig. 268. Radiograph.

OBLIQUE ANKLE PROJECTION (Figs. 266–268)

Special Projection:

Film: Secure film-holder in vertical plane.
Foot: Place medial border of the foot at a 45 degree angle with the film-holder and the posterior aspect of the ankle and heel in contact with the film-holder.
X-Ray: Direct the central ray perpendicular to the film.

Centering:

Aim the central ray at the junction of the ankle joint.

Radiograph:

An oblique view of the fibula is visualized with the distal end free from overlapping images of tibia and talus
The tibio-fibular joint
The talo-fibular joint

TABLE 12
Oblique Ankle Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small ankle 45 Kv —3 sec	
Medium ankle 55 Kv —3 sec	
Large ankle. 65 Kv —2¼ sec	
Distance 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing.

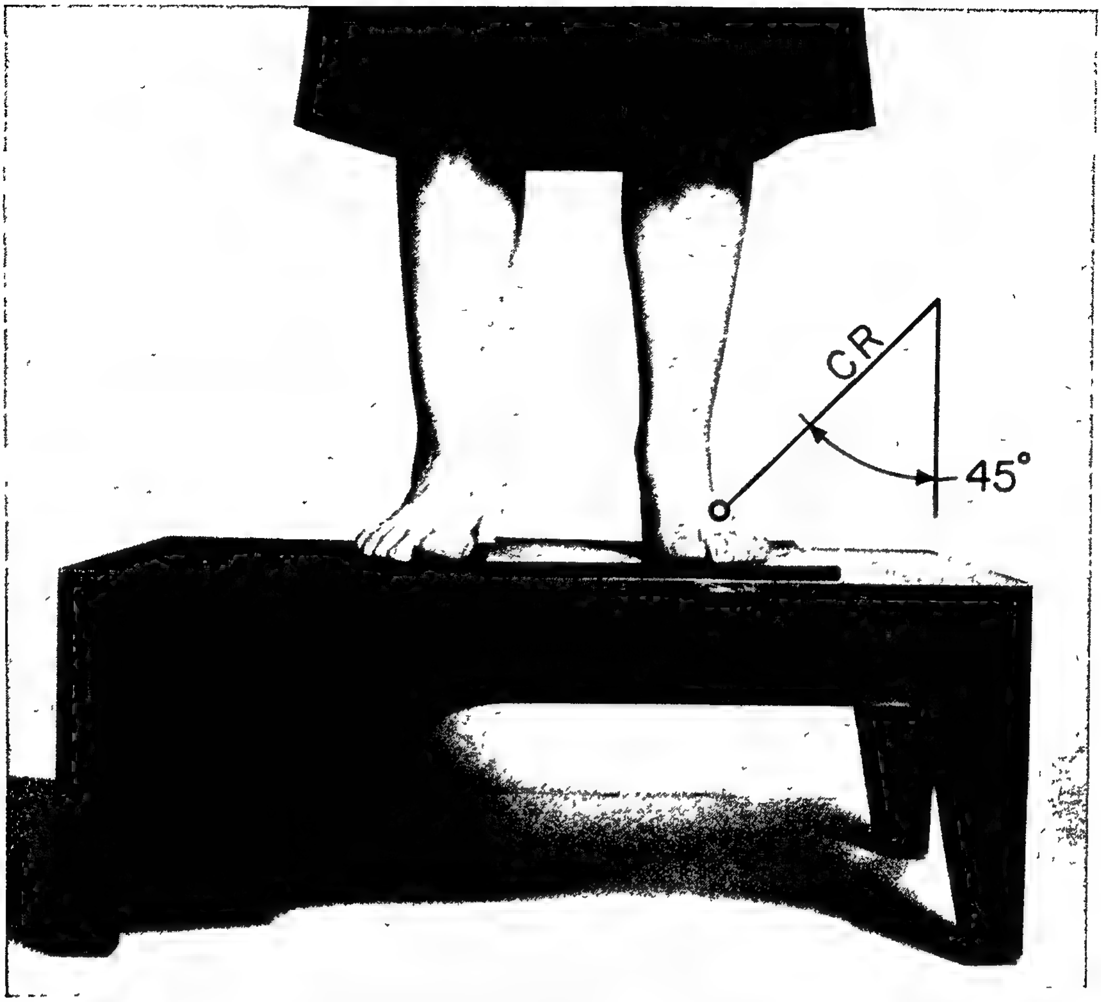


FIG 269. Special Oblique Foot Projection.

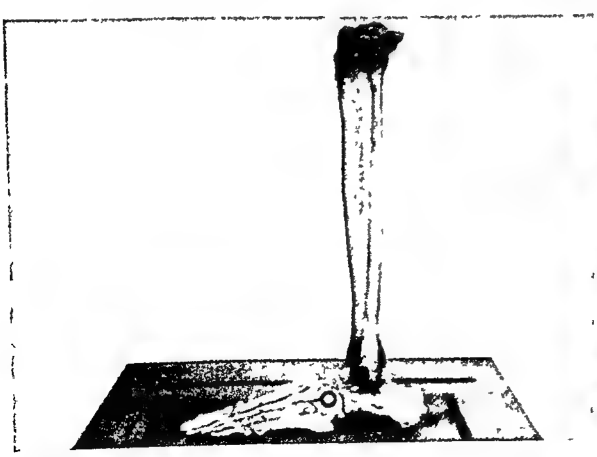


FIG 270. Centering.

FIG. 271 Radiograph.

OBLIQUE FOOT PROJECTION (Figs. 269–271)

Special Projection:

Film: Place the film-holder on top of the Ortho-x-poser.
Foot: Pose the patient with feet at wide stance. Place one foot on the film-holder close to the side, because the obliquity of the ray will move the image toward the center of the film.
X-Ray: Direct the central ray from a 45 degree angle from the vertical plane.

Centering:

Aim central ray at the dorsum of the cuboid. Use base of fifth metatarsal for landmark.

Radiograph:

The cuboid in complete profile.
Lateral cuneiform
Navicular
Calcaneus
Talus
Semi-lateral view of all metatarsals and phalanges

TABLE 13
Oblique Foot Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot: 45 Kv —2¾ sec	
Medium foot: 55 Kv —2 sec	
Large foot 65 Kv.—2 sec.	
Distance 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing

Fig. 272 Special Axial Sesamoid Projection.

Fig. 273. Centering.

Fig. 274. Radiograph.

AXIAL SESAMOID PROJECTION (Figs. 272–274)

Special Projection:

Film: Place the film-holder on top of the Ortho-x-poser.
Foot: Patient standing, holding foot under examination in flexed position at metatarso-phalangeal joint.
X-Ray: Direct the central ray from an angle that will carry it below the heel to avoid superimposing images.

Centering:

Aim central ray at the point of contact of the sesamoid and metatarsal head area.

Radiograph:

Axial view of the sesamoid bones of the hallux
Articular area of sesamoid bones and first metatarsal bone
Plantar aspect of metatarso-phalangeal joints

TABLE 14

Axial Sesamoid Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot 45 Kv —2¾ sec.	
Medium foot 55 Kv.—2 sec	
Large foot. 65 Kv —2 sec.	
Distance 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing.

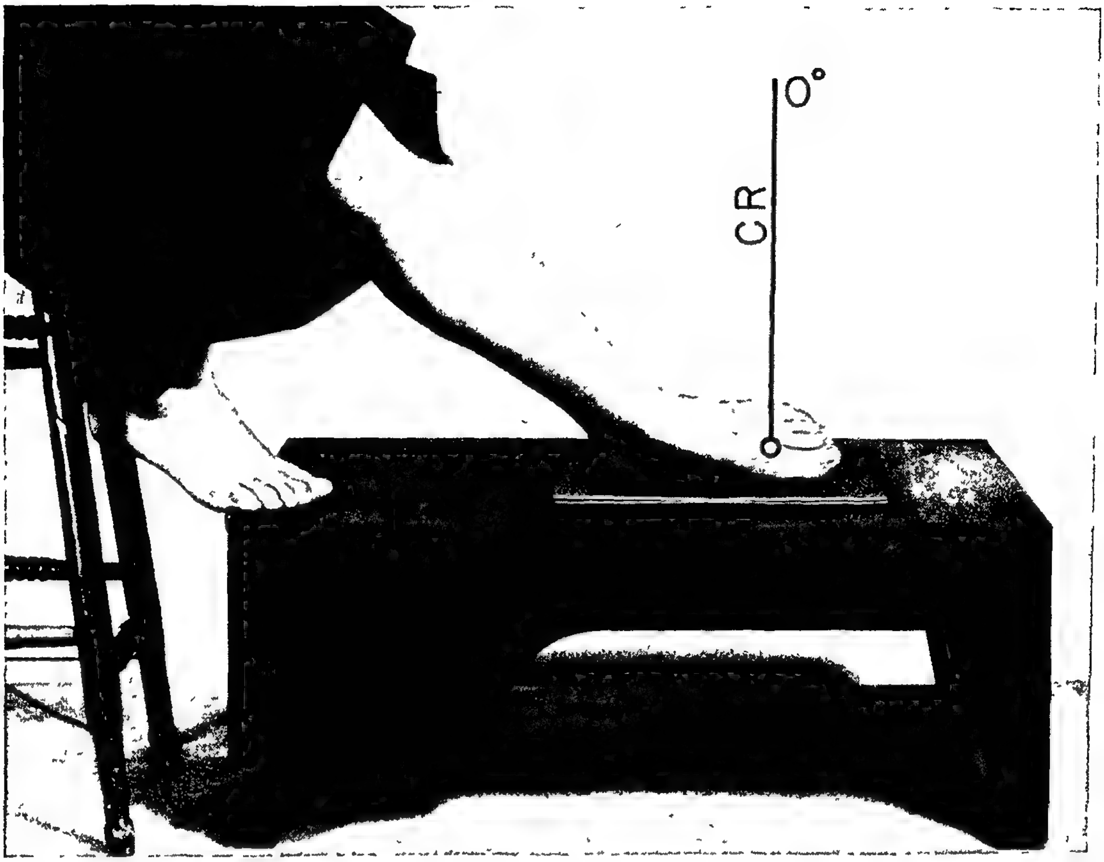


Fig 275 Special Dorso-medial Foot Projection

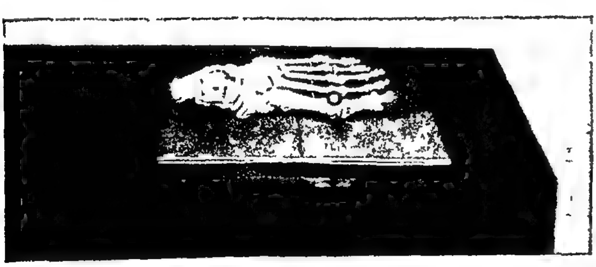


Fig. 276. Centering.

Fig. 277. Radiograph.

DORSO-MEDIAL FOOT PROJECTION (Figs. 275–277)

Special Projection:

Film: Place the film-holder on top of the Ortho-x-poser.

Foot: Medial border of foot in contact with film-holder. The sole of the foot is raised so that it places the foot at a 45 degree angle. Patient may be seated.

X-Ray: Direct the central ray from an absolutely vertical plane of exposure.

Centering:

Aim the central ray at the head of the first metatarsal bone.

Radiograph:

Dorsal aspect of first metatarsal bone and metatarso-phalangeal joint
Oblique view of toes
Oblique views of third, fourth and fifth metatarsal bones
Medial sesamoid in lateral superimposed profile

TABLE 15

Dorso-medial Foot Position

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot: 45 Kv.—2½ sec.	
Medium foot 55 Kv.—1½ sec	
Large foot. 65 Kv.—1½ sec.	
Distance 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing.

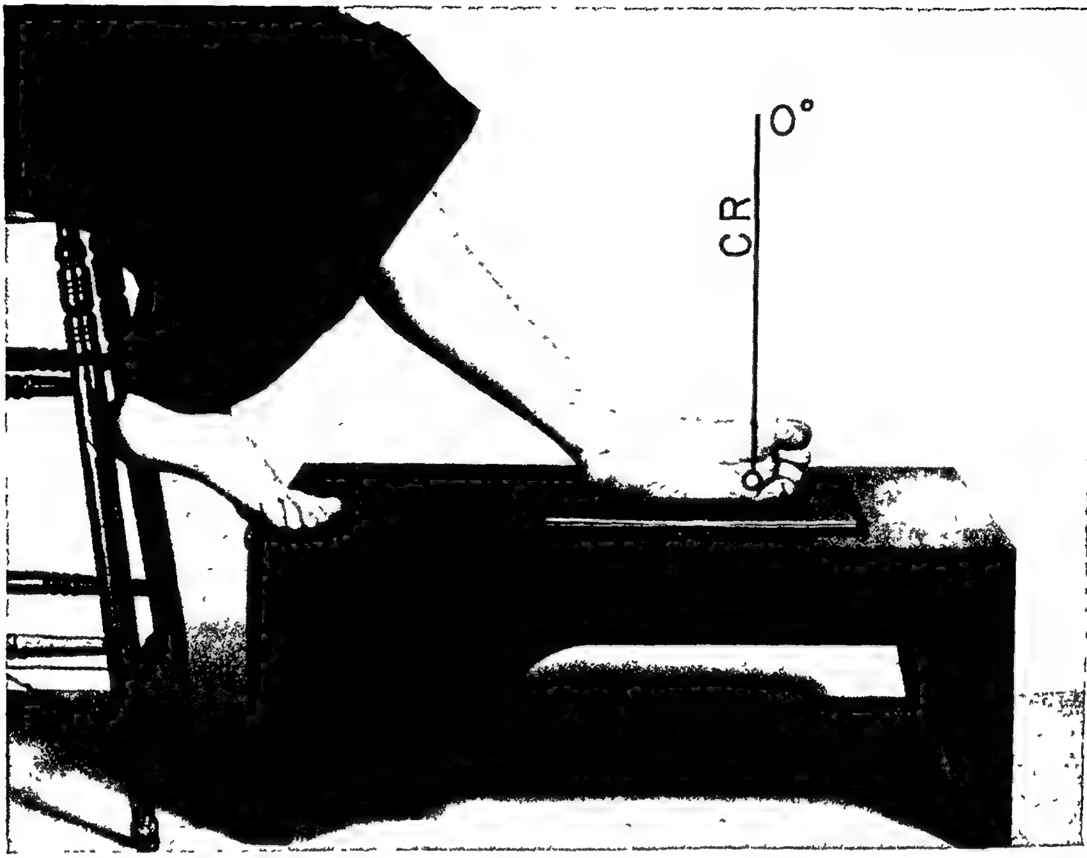


Fig. 278. Special Plantar-lateral Foot Projection.

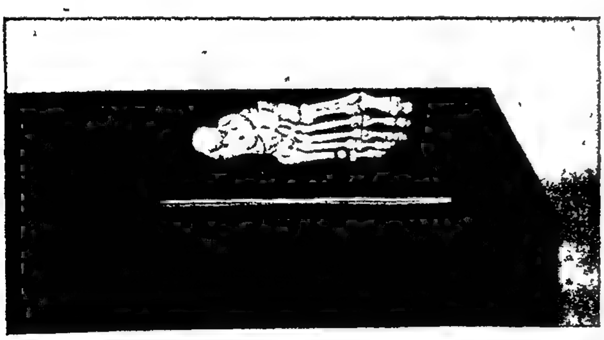


Fig 279 Centering

Fig 280 Radiograph.

PLANTAR-LATERAL FOOT PROJECTION (Figs. 278–280)

Special Projection:

Film: Place the film-holder on top of the Ortho-x-poser.

Foot: Lateral border of the foot in contact with film-holder. The foot is turned on the dorsum so that the sole faces upward. Patient may hold hand on knee to steady the position. Patient usually seated.

X-Ray: Direct the central ray from an absolutely vertical plane of exposure.

Centering:

Aim the central ray at the base of the fifth metatarsal bone.

Radiograph:

Anatomical structures visualized to advantage
Lateral view of the fourth and fifth metatarsal bones

TABLE 16
Plantar-lateral Foot Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot. 45 Kv.—2½ sec.	
Medium foot 55 Kv —1½ sec.	
Large foot: 65 Kv.—1½ sec	
Distance: 24 inches anode-film	
Milliamperage· 10 Ma	

No-screen film—Potent solutions—Time and temperature processing.

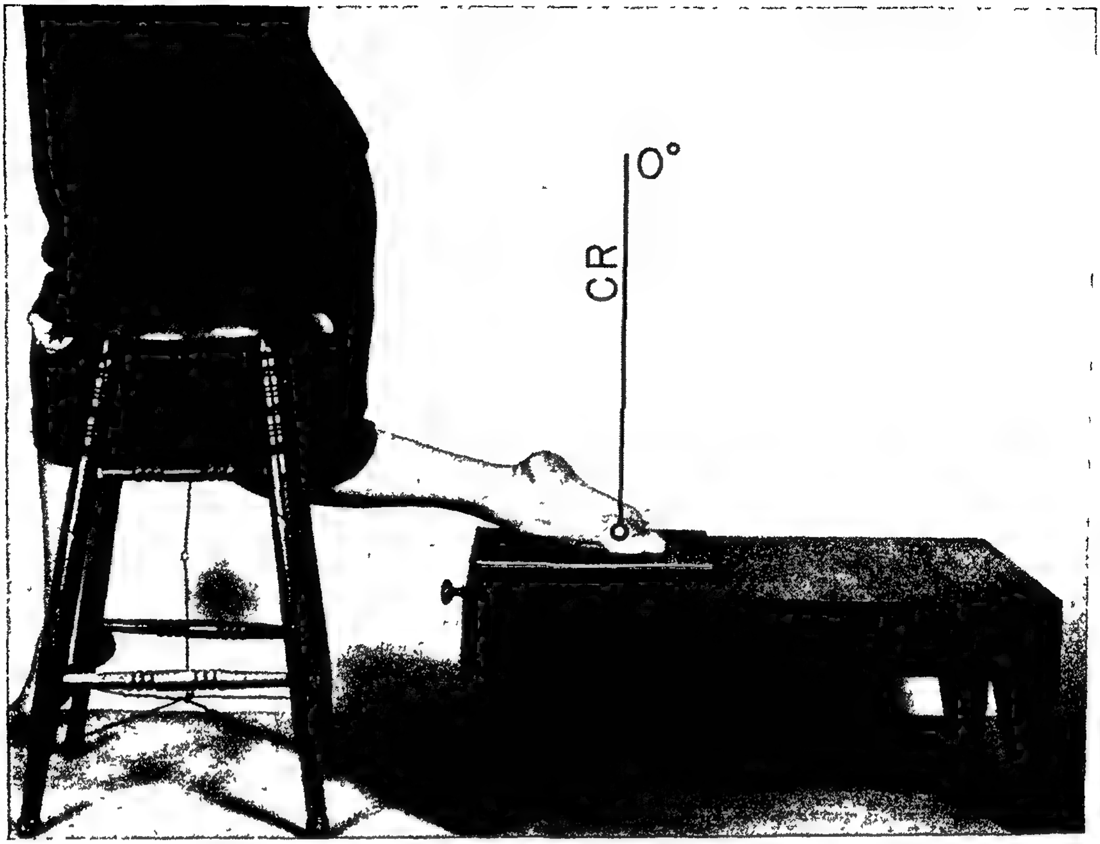


Fig 281. Special Plantar-medial Foot Projection.

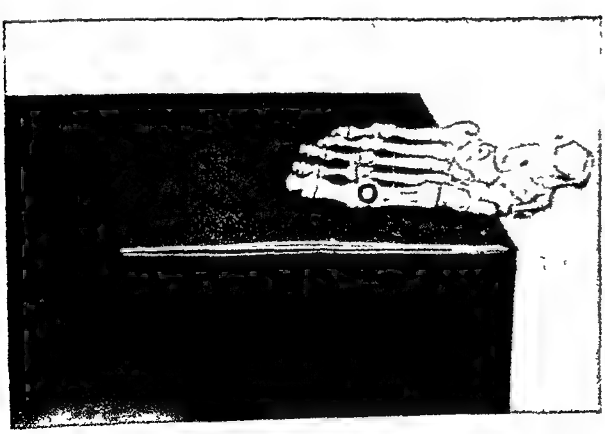


Fig. 282. Centering.

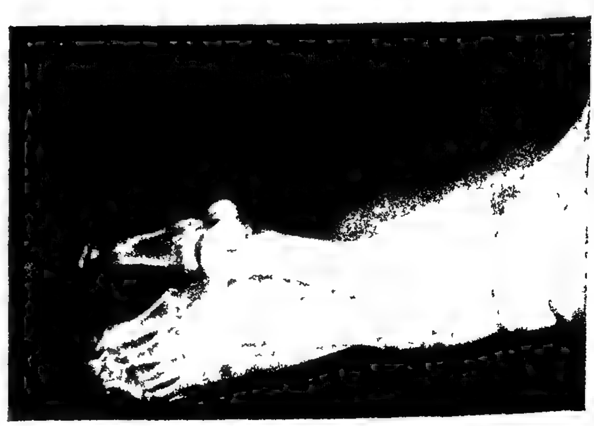


Fig. 283. Radiograph.

PLANTAR-MEDIAL FOOT PROJECTION (Figs. 281–283)

Special Projection:

Film: Place the film-holder on top of the Ortho-x-poser at the corner.

Foot: With patient half seated on a stool facing opposite direction from Ortho-x-poser, bend knee and place the dorsum of the foot on the film-holder so that medial border is in contact.

X-Ray: Direct the central ray from an absolutely vertical plane of exposure.

Centering:

Aim the central ray at the first metatarso-phalangeal joint.

Radiograph:

A lateral view of the medial sesamoid bone
The plantar aspect of the first metatarso-phalangeal joint

TABLE 17
Plantar-medial Foot Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot: 45 Kv —2½ sec.	
Medium foot. 55 Kv.—1½ sec	
Large foot. 65 Kv —1½ sec	
Distance· 24 inches anode-film	
Milliamperage 10 Ma.	

No-screen film—Potent solutions—Time and temperature processing.

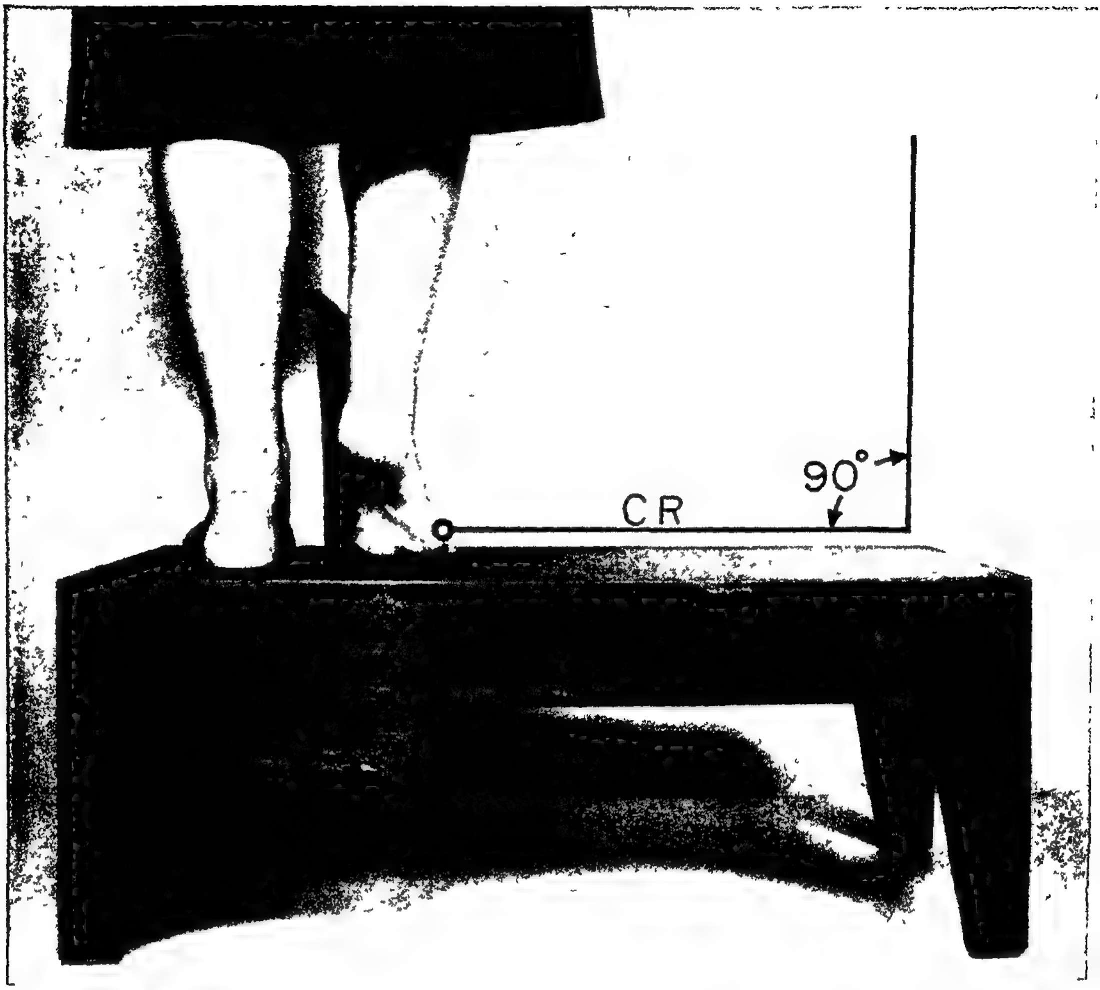


FIG. 284. Functional First Metatarso-phalangeal Joint Projection.

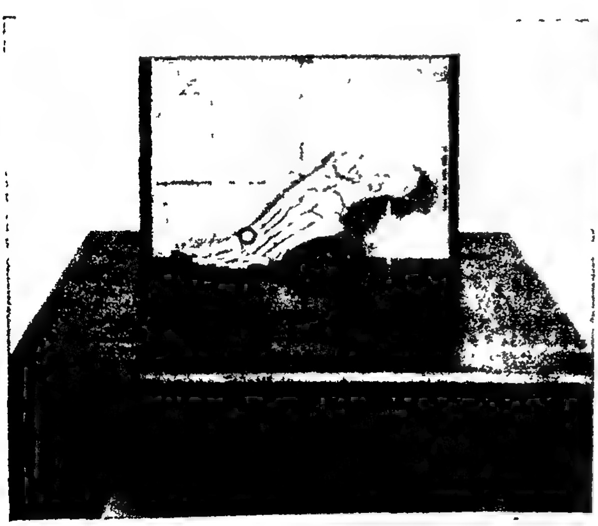


FIG. 285. Centering.

FIG. 286 Radiograph.

FUNCTIONAL FIRST METATARSO-PHALANGEAL JOINT PROJECTION (Figs. 284–286)

Functional Projection:

Film: Secure film-holder in vertical plane.

Foot: Pose the patient in standing position with the inner border of the foot in contact with the film-holder. Instruct patient to raise the foot keeping toes in contact with the platform until the full range of motion is executed at the metatarso-phalangeal joint, or until pain is elicited. Let the heel contact the film-holder for stability.

X-Ray: Direct central ray parallel with the top of the Ortho-x-poser, at a 90 degree angle from the vertical plane.

Centering:

Aim central ray perpendicular to the film at the head of the first metatarsal.

Radiograph.

The range of motion obtained in extension of the first metatarso-phalangeal joint

TABLE 18

Functional First Metatarso-phalangeal Joint Projection

Suggested Technical Factors	Adjust Chart for Unit in Use
Small foot 45 Kv —2½ sec	
Medium foot 55 Kv —2½ sec	
Large foot 65 Kv.—2½ sec	
Distance. 24 inches anode-film	
Milliamperage 10 Ma	

No-screen film—Potent solutions—Time and temperature processing

Chapter XVIII

Radiography of Selected Foot Conditions

A radiographic study of a foot condition requires enough radiographic views of the area to provide complete diagnostic information. To portray a specific foot condition satisfactorily, it is highly desirable that reasonable uniformity of radiographic views be obtained. A number of factors affect the selection of projections and the arrangement of the views.

COMPOSING A RADIOGRAPHIC EXAMINATION

Basic Views Necessary for Diagnosis. In order to make a comprehensive x-ray examination, it is always necessary to make exposures from two divergent planes. The most acceptable planes of exposure are generally those that will result in a plan view and an elevation view of the part. From these two views one may visualize the third dimensional characteristics portrayed by the radiograph. The site of the lesion is generally demonstrated by one or the other of the two views. If these basic views do not completely identify the lesion to the satisfaction of the doctor, he may take additional exposures from any position that will add information to the case

The Composite Radiograph. In the interest of film economy it is common practice to make more than one radiographic exposure on the same film. Independent lead-blockers are manipulated to protect portions of the film, and the ray-proof well of the Ortho-x-poser is used to advantage. It is, however, poor practice to crowd too many views on a film, especially when no margin of density is available to profile the area under inspection Soft tissue is of diagnostic importance and in most instances should be a feature of the radiograph Rather than crowd a film or arrange it poorly, a single film for each radiographic position would be preferable Of course, it is inconvenient to have to handle four individual films in viewing a case when four views could be nicely arranged on one film.

Consideration must be given to the arrangement of the various views on the finished film They should be arranged in such a manner as to provide convenience in interpretation. In order to present a radiograph of orderly appearance, toes should be pointed in the same direction when several views are developed on the same film.

Conditions Prevailing in a Specified Area: There are certain conditions that are peculiar to certain bones or groups of bones: e.g., calcaneal exostosis, Frieberg's infraction of the second metatarsal, sesamoiditis, etc. When a condition is considered a diagnostic possibility, the examination may be restricted to the area involved.

When there is any doubt as to the extent of the problem, the entire foot must be radiographed A severely wrenched foot may disclose, on radiographic examination, fractures due to avulsion in an area far removed from the site of subjective findings. This occurs in fractures of the base of the fifth metatarsal concomitant with ankle sprain.

An entire foot survey examination should be made in all patho-anatomical problems. This procedure insures a comprehensive analysis of all of the foot bones and their alignment.

Film Identification: Each film used in a radiographic examination should bear basic identification information consisting of the patient's name, the date, and the doctor's name and city. As each view is performed, the proper designation of right or left must be applied. If this is done there is no possible margin of error in identity of the foot under examination.

POSING THE PATIENT

Skill and tact should be exercised in managing the patient during the x-ray examination.

Make the patient as comfortable as possible at all times during the examination. When a particularly difficult position must be assumed, it is often helpful for the operator to first assume the position as a demonstration for the patient to follow. When the patient must be moved from left to right while in standing position, he may be directed by telling him to face the appropriate side of the room.

In orthopedic cases it is well to remember that the examination should record the foot condition as it exists while the patient is posed in his habitual posture.

In making a lateral projection of the foot, it is first necessary to place the foot under inspection parallel with the film, then to allow the patient to adjust the indifferent foot until he feels posed naturally, with body-weight distributed equally on both feet (Fig. 291).

In recording a dorso-plantar projection the patient should place the foot under inspection on the film-holder in a natural pose. The indifferent foot may then be posed irrespective of the film-holder in its natural position

To emphasize the need for posing the patient in habitual stance, let us assume that a subject has abducted and everted feet typical of arch depression. The foot under inspection for a lateral view should be placed in parallel contact with the film and the indifferent foot placed in its natural, abducted position. The patient's body should also swing to a natural position and not be turned. If these posing directions are ignored, and the patient places both feet parallel with the film, the foot will be forced into an improved alignment so that the radiograph does not reveal the true status of the foot The same situation exists in the

dorso-plantar view. The position may be facilitated by laying the film-holder on the top of the Ortho-x-poser at the approximate angle of abduction. The patient then poses the foot under inspection in natural stance on the film-holder and places the indifferent foot in natural pose rather than parallel on the film-holder (Fig. 292).

DEMONSTRATIONS OF STEP-BY-STEP TECHNIQUE (Figs. 287–334)

It is an art to be able to complete a radiographic examination quickly, thoroughly, accurately, and with minimum confusion to the patient. In the step-by-step technique the radiographic projections are developed in a sequence that makes for maximum efficiency. The identification marker is usually applied in the first position so that it is not overlooked.

The patient is carried through a minimum number of movements and the protection of the film by manipulation of film-blockers is simplified. The projection technique and technical factors for the various positions are given in the previous chapter regarding projection technique.

In the illustrated series that follows the radiograph shows the condition. In addition to the entire foot survey, the major foot conditions are included:

Entire Foot Survey
Supplementary Examination
Forefoot Study
Ankle Area and Base of Fifth Metatarsal
Ankle Area
Heel Study
Single Toe Examination
Comparative Forefoot Study
Quinti Digiti Varus
Hallux Limitus
Sesamoiditis
Frieberg's Infraction of Metatarsal Head

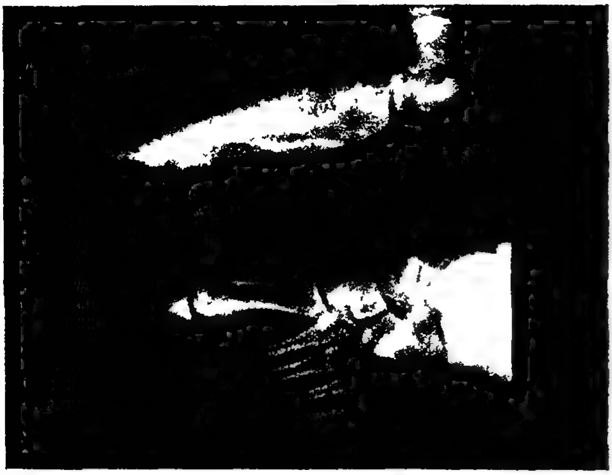


FIG. 287. Comparative Study of Entire Foot (Left Foot). Patho-anatomical foot conditions and all non-specific foot conditions.

FIG. 288. Comparative Study of Entire Foot (Right Foot).

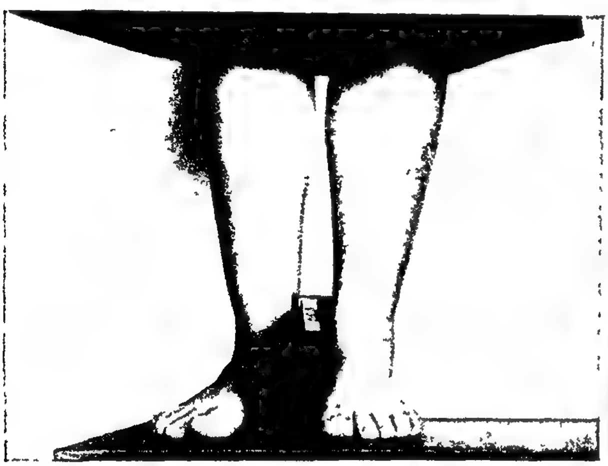


FIG 289 (1) Lateral Position Left Foot

FIG 290 (2) Dorso-plantar Position Left Foot

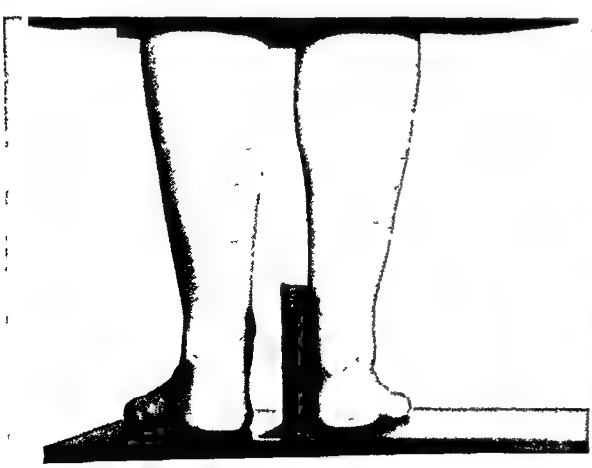


FIG 291 (3) Lateral Position Right Foot.

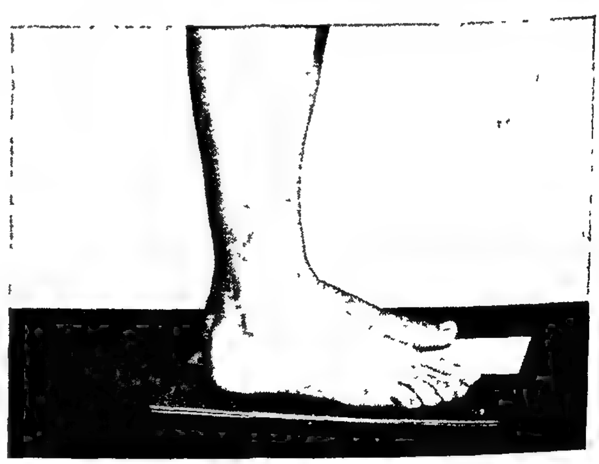


FIG 292 (4) Dorso-plantar Position Right Foot

ENTIRE FOOT SURVEY (Figs. 287–292)

(a) Patho-anatomical Foot Conditions

(b) All Non-specific Conditions

One film devoted to the examination of each foot.
Comparative study requires two films (Figs. 287, 288).

Sequence:

(1) Lateral Position—Left foot (Fig. 289).
Half of film protected in ray-proof well of Ortho-x-poser.
Identification marker in place at toe end.

(2) Dorso-plantar Position—Left foot (Fig. 290).
Film-holder placed on an angle on top of Ortho-x-poser to anticipate abducted foot posture.
Lead-blocker covers half of film previously exposed.

(3) Lateral Position—Right Foot (Fig. 291).
Patient has reversed position and half of film is protected in ray-proof well of Ortho-x-poser.
Identification marker in place at toe end (not shown).

(4) Dorso-plantar Position—Right Foot (Fig. 292).
Film-holder placed on an angle on top of Ortho-x-poser to anticipate abducted foot posture.
Lead-blocker covers half of film previously exposed.

FIG. 293 Supplementary Examination in Patho-Anatomical cases. All non-specific foot conditions (Comparative).

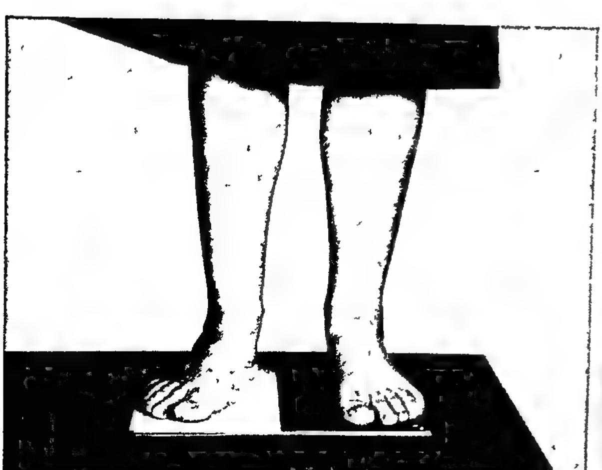


FIG. 294 Oblique Position Left Foot

FIG 295 Oblique Position Right Foot.

SUPPLEMENTARY EXAMINATION (Figs. 293–295)

(a) Supplementary Examination in Patho-anatomical Cases

(b) All Non-specific Foot Conditions

One film includes comparative study of both feet (Fig. 293).

Sequence:

(1) Oblique Position—Left Foot (Fig. 294).
Film-holder placed on Ortho-x-poser with lead-blocker protecting half of film length.
Foot placed near edge of film because the oblique projection will record image toward middle of film.
Identification marker placed at heel end (not shown).
Left Marker at toe end.

(2) Oblique Position—Right Foot (Fig. 295).
Patient has reversed position.
Film-holder has been reversed.
Lead-blocker covers portion of film previously exposed.
Foot placed near edge of film.
Right marker at toe end (not shown).

FIG. 296. Fracture of Metatarsal or Phalanx Metatarsalgia, Hallux Valgus, Hammer Toe, Orthodigital Conditions.

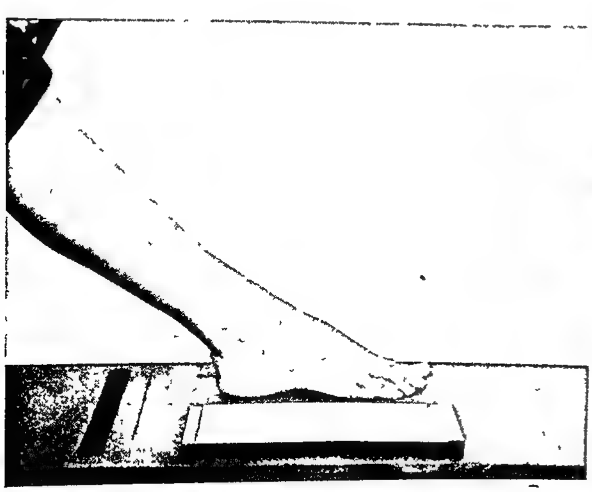


FIG 297. (1) Dorso-plantar Position.

FIG 298. (2) Dorso-medial Position.

FOREFOOT STUDY (Figs. 296–298)

(a) Metatarsalgia

(b) Hallux Valgus

(c) Hammer Toe

(d) Fracture of Metatarsal or Phalanx

(e) Orthodigital Conditions

One film devoted to the examination of each foot (Fig. 296).

Sequence:

(1) Dorso-plantar Position (Fig. 297).
Film-holder placed on Ortho-x-poser with lead-blocker protecting half of film.
Foot placed on unprotected portion. Patient may be seated.
Identification marker placed at toe end.

(2) Dorso-medial Position (Fig. 298).
Lead-blocker covers portion of film previously exposed.
Foot positioned over unexposed area.

Fig 299. Ankle Area and Base of Fifth Metatarsal.

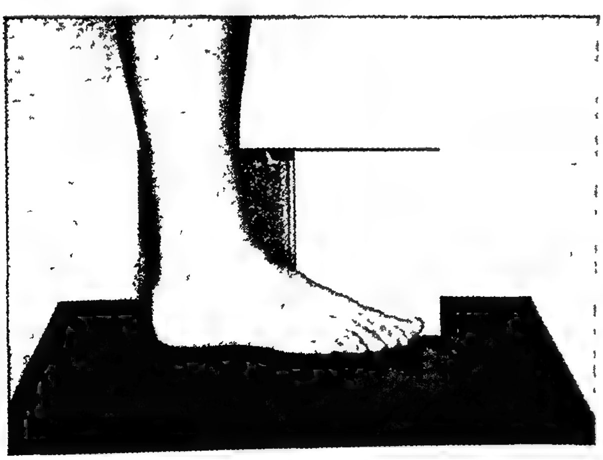


Fig. 300 (1) Lateral Ankle Position

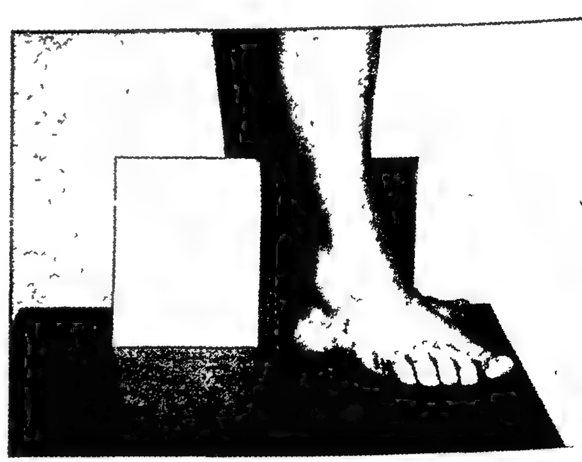


Fig 301 (2) Oblique Ankle Position.

ANKLE AREA AND BASE OF FIFTH METATARSAL (Figs. 299–302)

To be used when pain and swelling include region of the base of the fifth metatarsal bone (Fig. 299).

Sequence:

(1) Lateral Ankle Position (Fig. 300).
Lower portion of film protected in ray-proof well of Ortho-x-poser. Half of portion of film above Ortho-x-poser protected with lead blocker.
Foot and ankle placed in contact with unprotected portion of film. Be sure cuboid and base of fifth metatarsal is included.
Identify right or left foot.

(2) Oblique Ankle Position (Fig 301).
Lead-blocker is moved to protect portion of film previously exposed.
Foot is placed in position with ankle in contact with film-holder.

(3) Dorso-plantar Foot Position (Fig. 302).
Film-holder is removed from film-well and placed on top of Ortho-x-poser.
The entire area of film exposed in the two previous exposures is protected by lead-blockers.
The identification marker is placed at the end of the film, including left or right.
Foot is placed in position on the film-holder.

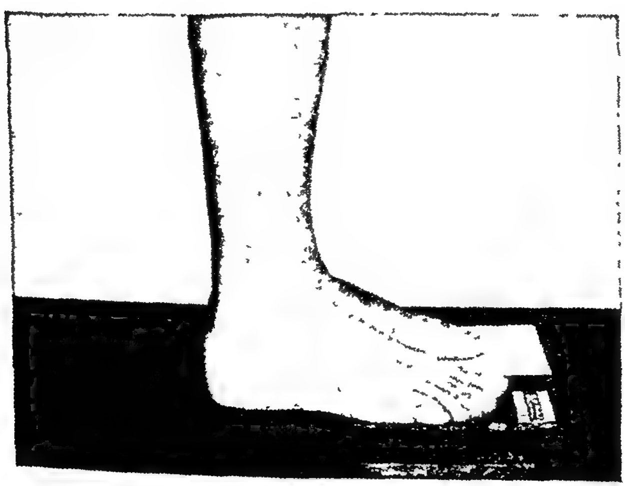


FIG 302 (3) Dorso-plantar Foot Position.

Fig 303 Ankle Area and Lower Third of Leg

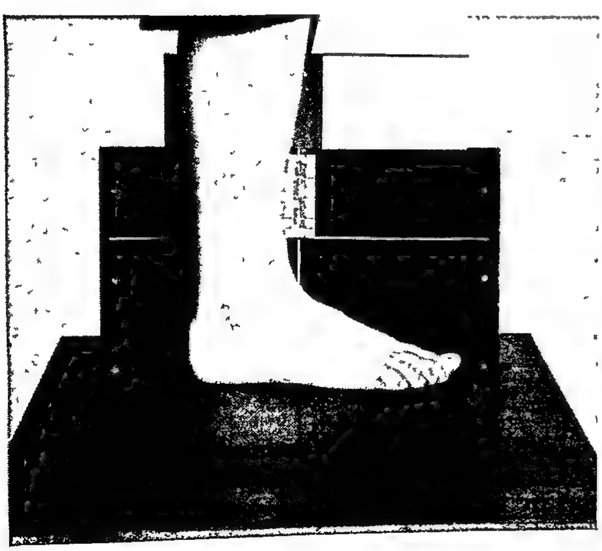


Fig. 304 (1) Lateral Ankle Position

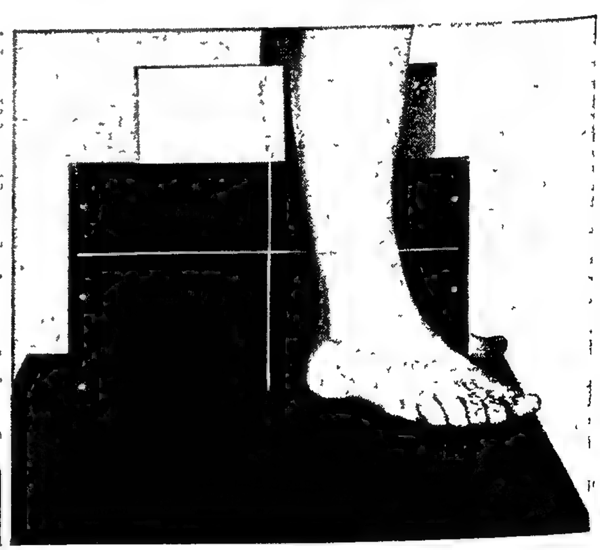


Fig 305. (2) Oblique Ankle Position.

ANKLE AREA (Figs. 303–305)

To be used when pain and swelling rises above ankle (Fig. 303).

Sequence:

(1) Lateral Ankle Position (Fig. 304).
The film-holder is placed in a radio-lucent film-holder tunnel, and half of the film is protected with a lead-blocker.
Identification marker is applied to an area that is free.
Lower third of leg and foot is placed in front of film.

(2) Oblique Ankle Position (Fig. 305).
Lead-blocker moved to cover portion of film previously exposed.
Foot positioned in front of film.
Identity of left or right foot marked.

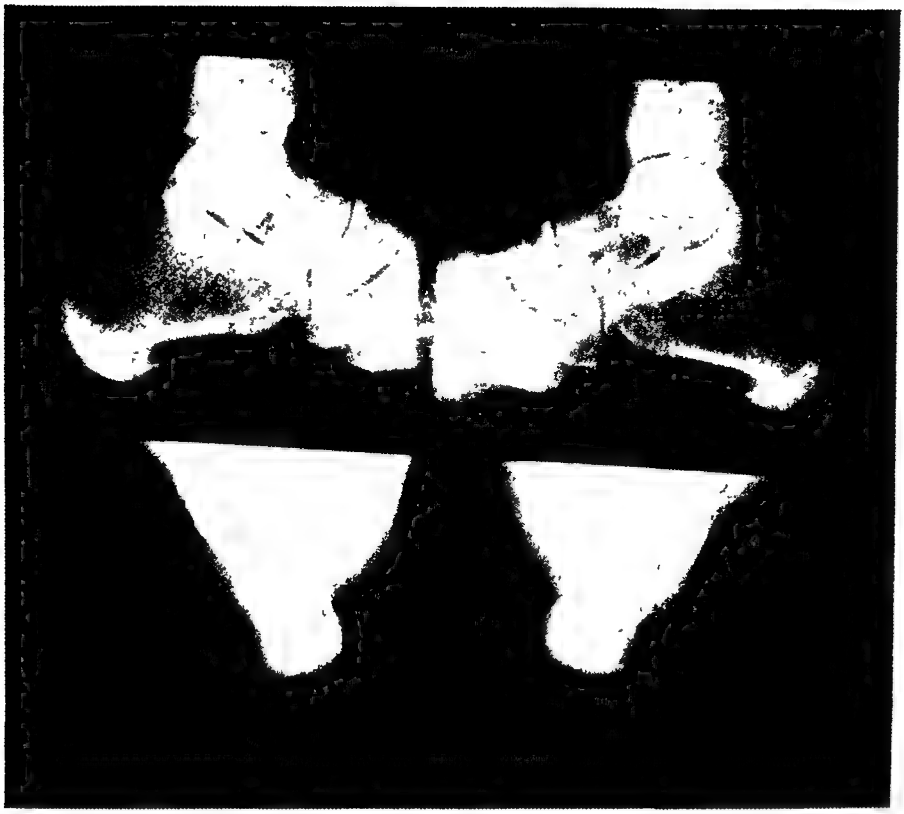


FIG. 306. Heel Study (Comparative).

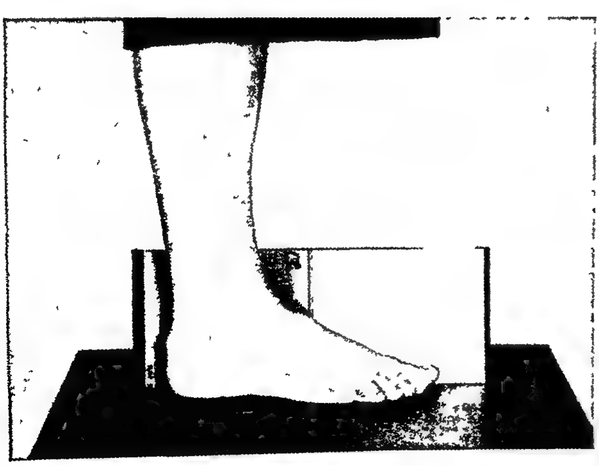


FIG 307. (1) Lateral Foot Position—Right Heel.

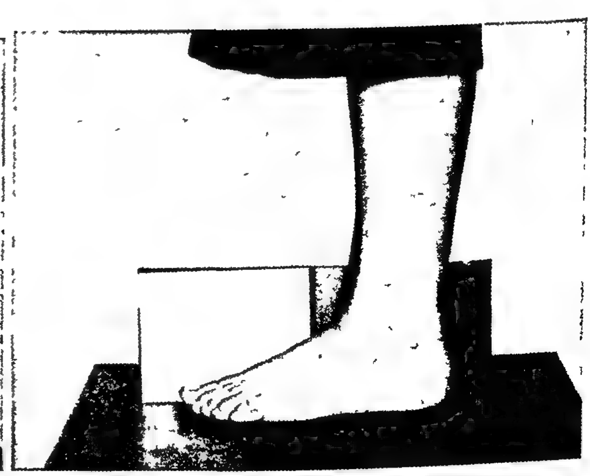


FIG. 308. (2) Lateral Foot Position—Left Heel.

HEEL STUDY (Figs. 306–309)

One film includes comparative study of both feet (Fig 306).

Sequence:

(1) Lateral Foot Position—Right Heel (Fig. 307).
Half of film protected in ray-proof well of Ortho-x-poser.
Half of portion above ray-proof well is protected with lead-blocker.
Foot placed in front of remaining quarter of film.
Right marker applied.

(2) Lateral Foot Position—Left Heel (Fig 308).
Lead-blocker moved to protect portion of film previously exposed.
Patient reverses position and left foot is placed in front of unexposed film.
Left marker applied

(3) Postero-plantar Calcaneus Position (Fig. 309).
Film-holder is removed from ray-proof well and placed on top of the Ortho-x-poser.
Lead-blocker covers half of film previously exposed
Patient places heel area on unexposed portion of film, the forefoot area on the lead-blocker Patient facing opposite direction from x-ray unit.
Identification marker placed on free area.
Left and right markers placed in position

Fig 309 (3) Postero-plantar Calcaneus Position.

Fig. 310. Subungual Exostosis: Single Toe Examination

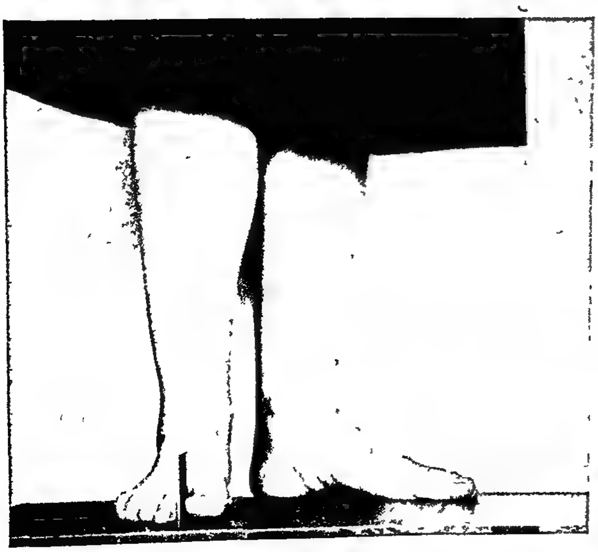


Fig 311 (1) Lateral Digital Position.

Fig 312. (2) Dorso-plantar Position

SINGLE TOE EXAMINATION (Figs. 310–312)

(a) Subungual Exostosis

One film devoted to the examination of a toe (Fig. 310).

Sequence:

(1) Lateral Digital Position (Fig 311).
Half of film protected in ray-proof well of Ortho-x-poser.
Identification marker at top of film.

(2) Dorso-plantar Position (Fig. 312).
Film-holder is removed from film-well and placed on top of Ortho-x-poser.
Lead-blocker covers portion of film previously exposed.
Toe positioned over unexposed area.

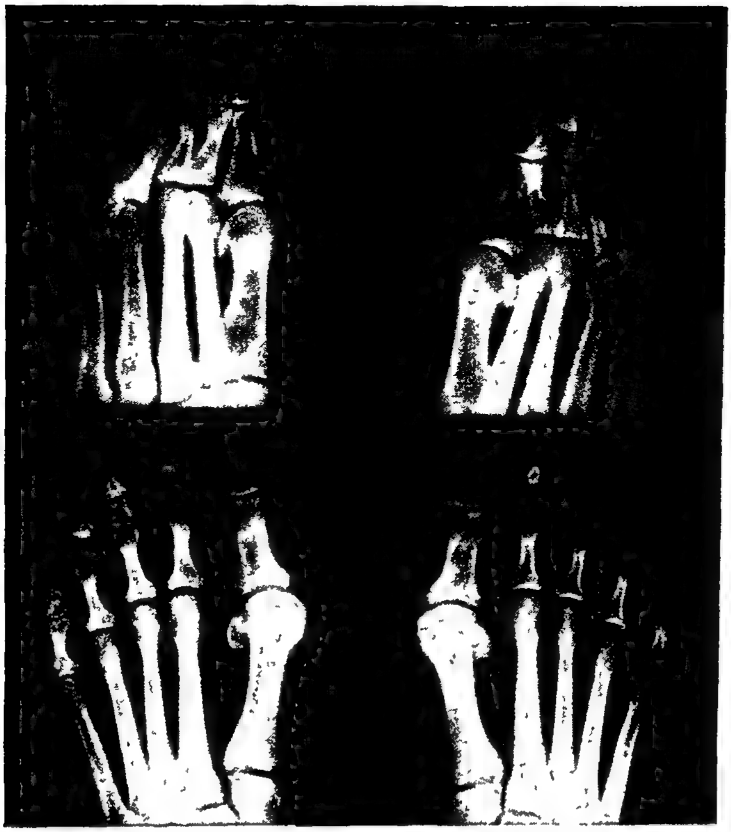


FIG. 313. HALLUX VALGUS Metatarsalgia, Hammer Toe, Fracture of Metatarsal or Phalanx, Orthodigital Conditions

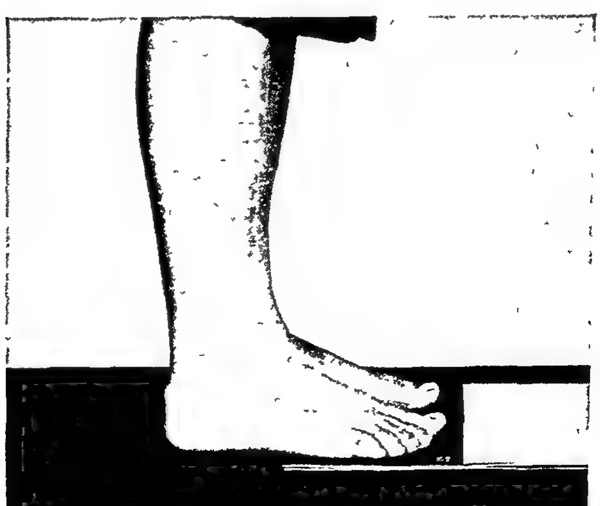


FIG 314 (1) Dorso-plantar Position

COMPARATIVE FOREFOOT STUDY (Figs. 313–316)

(a) Metatarsalgia

(b) Hallux Valgus

(c) Hammer Toe

(d) Fracture of Metatarsal of Phalanx

(e) Orthodigital Conditions

One film includes comparative study of both feet on one film (Fig. 313).

Sequence:

(1) Dorso-plantar Position (Fig. 314).
Film-holder placed on Ortho-x-poser with lead-blocker protecting half of film
Both feet, metatarsal area, placed on unprotected portion.

(2) Dorso-medial Position—Left Foot (Fig. 315).
Lead-blocker covers portion of film previously exposed.
Lead-blocker protects half of remainder leaving quarter of film exposed.
Identification marker applied at end of film-holder.
Left foot placed in position.

(3) Dorso-medial Position—Right Foot (Fig. 316).
Lead-blocker covers portion of film previously exposed.
Right foot placed in position.

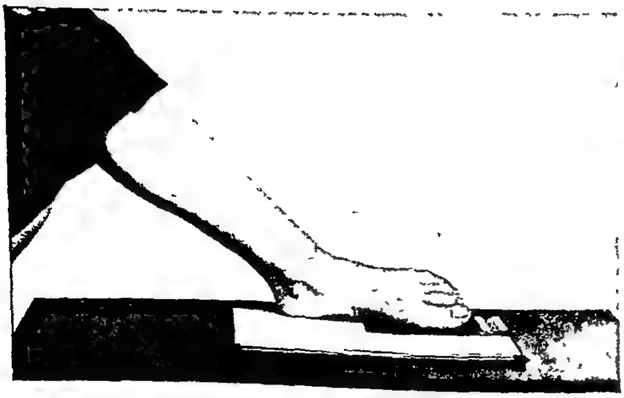


FIG. 315 (2) Dorso-medial Position Left Foot.

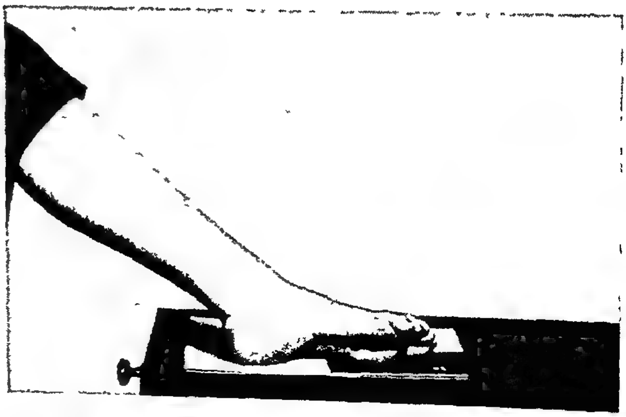


FIG. 316. (3) Dorso-medial Position Right Foot.

FIG 317. Quinti Digiti Varus (Comparative).

FIG. 318 (1) Dorso-plantar Position

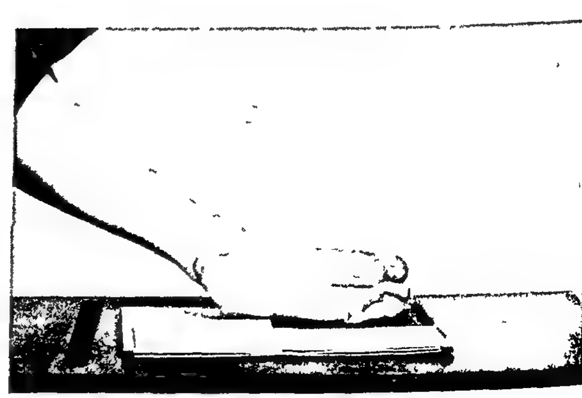


FIG 319 (2) Plantar-lateral Position Left Foot.

QUINTI DIGITI VARUS (Figs. 317–320)

One film includes comparative study of both feet on one film (Fig. 317).

Sequence:

(1) Dorso-plantar Position (Fig. 318).
Film-holder placed on Ortho-x-poser with lead-blocker protecting half of film
Both feet, metatarsal area, placed on unprotected portion.

(2) Plantar-lateral Position—Left Foot (Fig. 319).
Lead-blocker covers portion of film previously exposed.
Lead-blocker protects half of remainder, leaving quarter of film exposed.
Left foot placed in position.

(3) Plantar-lateral Position—Right Foot (Fig. 320).
Lead-blocker covers portion of film previously exposed.
Identification marker applied at end of film-holder.
Right foot placed in position.

FIG 320 (3) Plantar-lateral Position Right Foot

FIG. 321 HALLUX LIMITUS

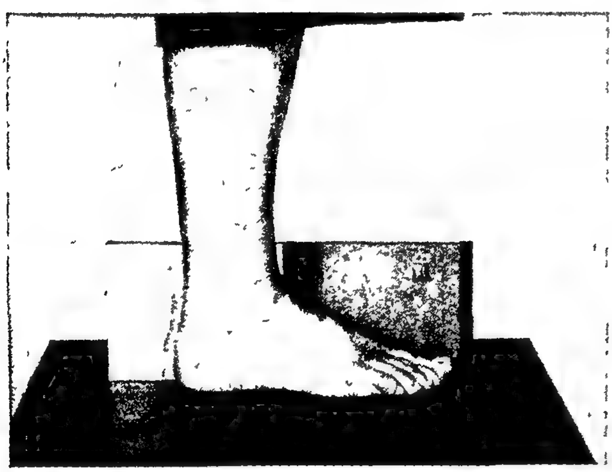


FIG 322 (1) Lateral Foot Position.

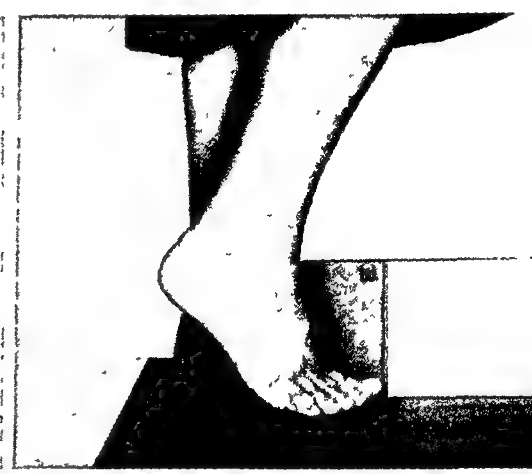


FIG. 323 (2) Functional Foot Position

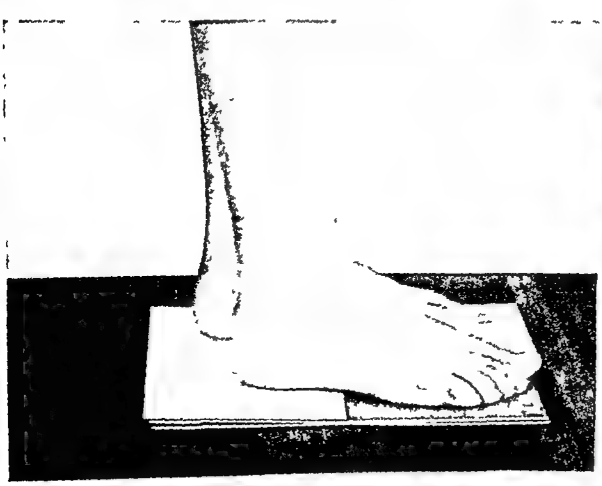


FIG. 324. (3) Dorso-plantar Foot Position.

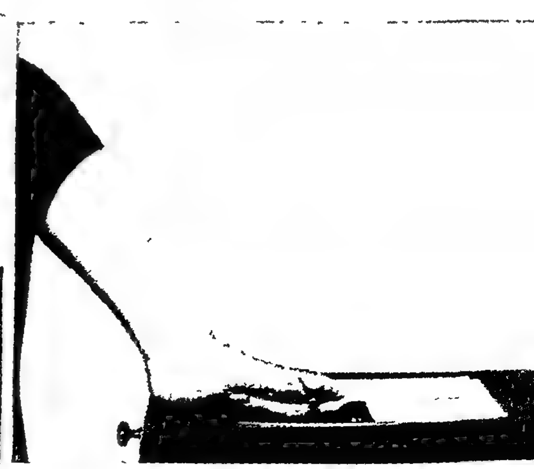


FIG. 325. (4) Dorso-medial Foot Position.

HALLUX LIMITUS (Figs. 321–325)

One film devoted to the examination of each foot.
Comparative study requires two films (Fig. 321).

Sequence:

(1) Lateral Foot Position—Right Forefoot (Fig 322).
Half of film protected in ray-proof well of Ortho-x-poser.
Half of portion above ray-proof well is protected with lead-blocker.
Forefoot placed in front of remaining quarter of film.
Identification marker applied.

(2) Functional Foot Position—Right Forefoot (Fig 323).
Lead-blocker moved to protect portion of film previously exposed
Patient moves foot into position in front of unexposed film and dorsiflexes foot until extent of range of motion at metatarso-phalangeal joint is reached

(3) Dorso-plantar Foot Position—Right Forefoot (Fig. 324).
Film-holder is removed from ray-proof well and placed on top of the Ortho-x-poser.
Lead-blocker covers half of film previously exposed
Lead-blocker covers half of remainder leaving quarter of film exposed.
Right foot placed in position.

(4) Dorso-medial Foot Position—Right Forefoot (Fig 325).
Lead-blocker is moved to cover portion just exposed.
Film-holder moved to end of Ortho-x-poser to facilitate positioning.
Dorso-medial position assumed with metatarso-phalangeal area over unexposed portion of film. Patient may be seated.

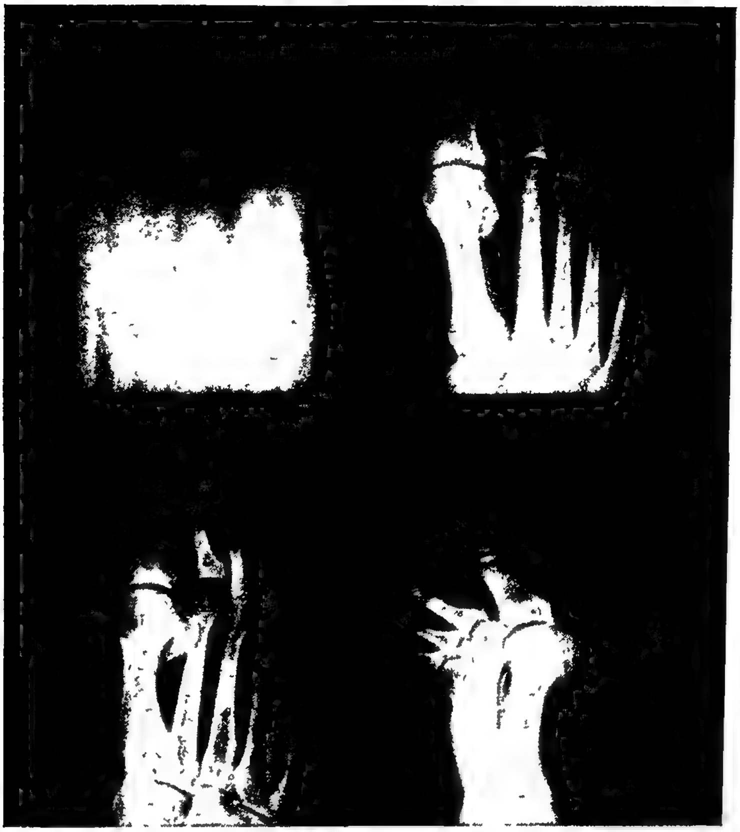


Fig 326 Sesamoiditis

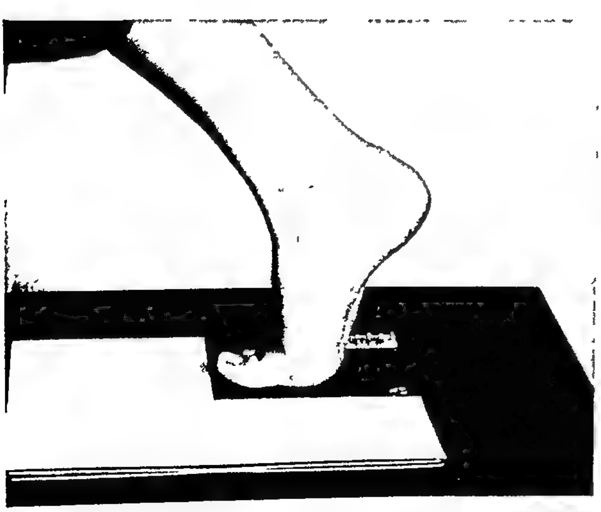


Fig 327. (1) Axial Sesamoid Position

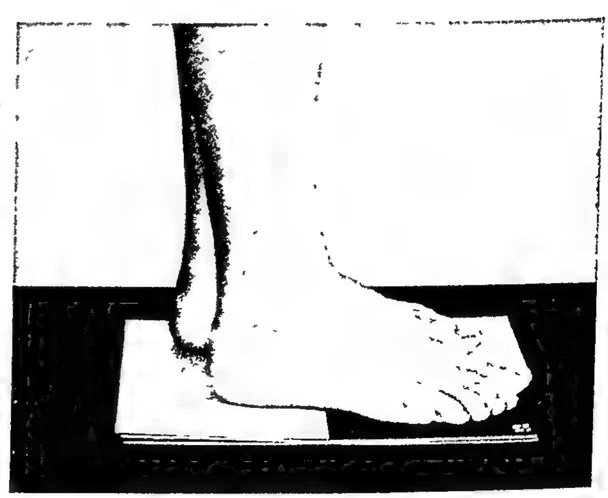


Fig 328 (2) Dorso-plantar Position.

SESAMOIDITIS (Figs. 326–330)

One film devoted to the examination of each foot (Fig. 326).
Comparative study requires two films.

Sequence:

(1) Axial Sesamoid Position (Fig. 327).
Film-holder placed on top of Ortho-x-poser.
Lead-blockers protect three-quarters of film.
Identification marker applied
Foot placed on unprotected portion and dorsi-flexed at metatarso-phalangeal joint. Patient faces away from x-ray unit.

(2) Dorso-plantar Position (Fig. 328).
Lead-blocker is moved to protect quarter of film previously exposed.
Patient turns toward x-ray machine and places foot in position over unexposed film.

(3) Dorso-medial Position (Fig. 329).
Lead-blocker is adjusted to permit lower quadrant of the film to be free for exposure.
Film-holder is moved to end of Ortho-x-poser to facilitate positioning.
Patient assumes position. Patient may be seated.

(4) Plantar-medial Position (Fig 330).
Lead-blocker is moved to protect previously exposed film
Film-holder moved to end of Ortho-x-poser.
Patient is seated with knee bent and foot placed in position.

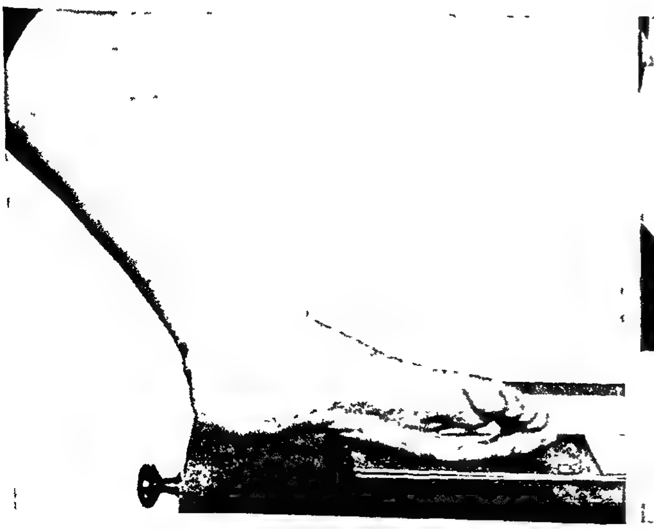


Fig 329 (3) Dorso-medial Position

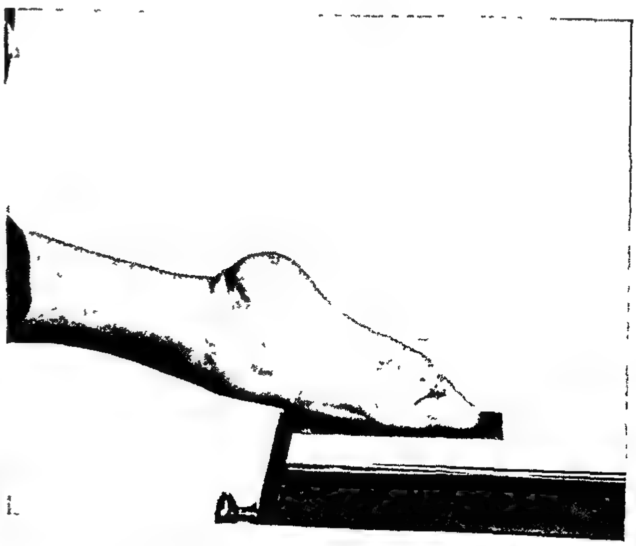


Fig 330 (4) Plantar-medial Position

FIG 331 Frieberg's Infraction of Metatarsal Head

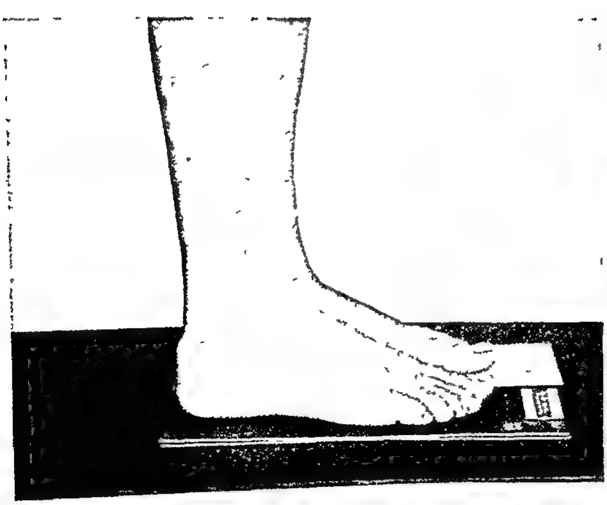


FIG 332 (1) Dorso-plantar Foot Position

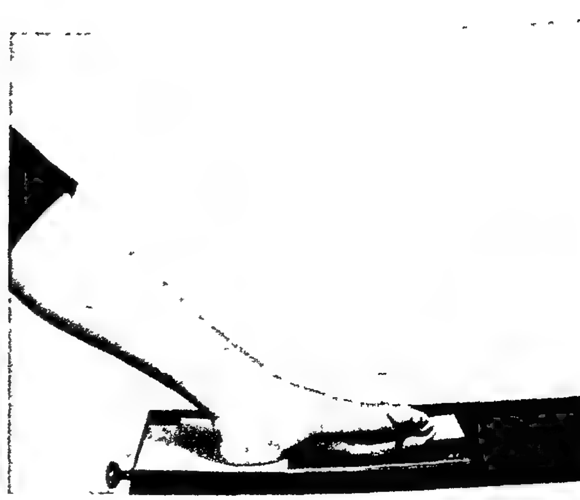


FIG 333 (2) Dorso-medial Foot Position.

FRIEBERG'S INFRACTION OF METATARSAL HEAD (Figs. 331–334)

One film devoted to the examination of each foot (Fig. 331).

Sequence:

(1) Dorso-plantar Foot Position (Fig. 332).
Film-holder placed on top of Ortho-x-poser
Lead-blocker protects one-half length of film.
Identification marker applied
Foot placed in unprotected portion in position.

(2) Dorso-medial Foot Position (Fig. 333).
Lead-blocker is moved to cover half of film previously exposed.
Lead-blocker protects third of remaining film.
With patient seated and film at end of Ortho-x-poser the foot is placed in position over unexposed film.

(3) Axial Sesamoid Position (Fig. 334).
Lead-blocker is moved to protect previously exposed two-thirds of film.
Patient faces away from x-ray unit and the foot is placed in dorsiflexed position over unexposed third of film

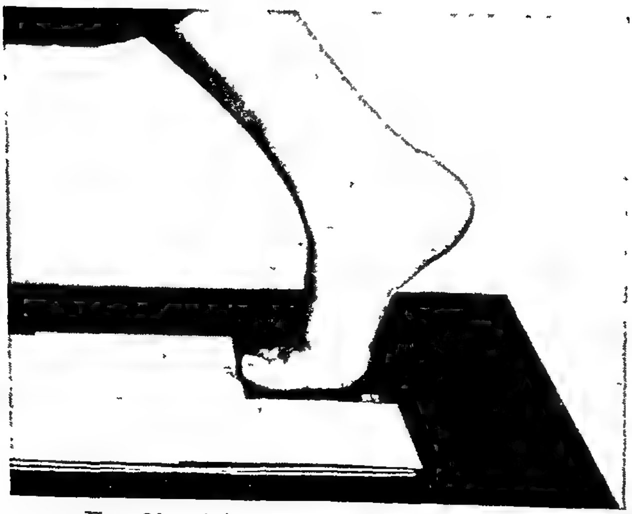


FIG 334 (3) Axial Sesamoid Position.

Chapter XIX

Special Roentgenographic Methods and Devices

Certain special techniques and devices of use to the practitioner of roentgenology will be dealt with in this chapter. Some of these are simple and may be performed with a minimum of apparatus; others are too complicated to perform with the present apparatus to be a part of routine technique.

The composite full-foot radiographic technique and the orthodynamic weight-distribution foot-imprint radiographic technique promise to be the most valuable developments in foot orthopedic procedure. These techniques have the added advantage that they may be performed with a minimum of apparatus.

Stereoscopy of the weight-supporting foot is a natural development resulting from the creation of the Ortho-x-poser. Many practitioners will find this technique an invaluable addition to their diagnostic armamentarium. Uniform radiographic exposure of the forefoot may be achieved by means of a new device. Under present conditions, radiographs in color are a luxury but they may become standard at a future date. Foot section radiographs are not routine because they are too complicated to perform with the apparatus currently available. Although this writer has initiated the use of many of these radiographic applications, it is hoped that others will advance them so that they will enjoy more wide-spread usage.

Also discussed in this chapter will be certain special procedures of which the practitioner should be aware and which he should use when the circumstances require them Among these are soft-tissue technique, venography, arteriography, fluoroscopy, and postural studies In addition, accessories employed in certain techniques will be discussed and their utility described. These accessories are the Potter-Bucky diaphragm, the Lysholm grid, angle blocks, translucent wedges, opaque wedges, and the vertical cassette holder.

THE COMPOSITE FULL-FOOT RADIOGRAPH

In the conventional dorso-plantar radiograph, the complete outline of the foot is lacking because the thickness of the leg and ankle causes an opacity that results in a panel of unexposed film in the hindfoot area (Fig. 338). A postero-plantar view permits visualization of the heel area only, with a panel of unex-

posed film in the forefoot area (Fig 337). Obviously, it would be impossible to use either of these radiographs as a guide in making an appliance, since the entire length of the foot could not be computed Also, it would be impossible to draw a baseline from the center of the heel through the foot radiograph to a point between the second and third metatarsal heads Such a baseline, if accurately demarcated, is, of course, of great value in determining the altered position of the bones in abnormal conditions

It is possible to make a composite radiograph on which the complete image is recorded (Fig 339). This is accomplished by making two exposures, a dorso-plantar projection (Fig 336) and then a superimposed postero-plantar one (Fig. 335) on the same film. The patient stands immobile during both exposures During each exposure the tube is brought close to the body, and the leg structures act as radiopaque shields The most accurate rendition is accomplished by exposing each foot separately. Care must be taken to center the ray along the axis of the foot from both front and hind positions. Careless centering may result both in overlapping shadows across the forefoot and double images Overlapping shadows may also occur when extremely thin leg structures do not afford an adequate protection for the forefoot The same situation may develop in cases of an extremely wide foot or of hallux valgus.

An acceptable radiograph of both feet may be made by posing the feet parallel and close together. In the dorso-plantar projection the central ray is directed precisely between the feet at the level of the head of the talus. In the postero-plantar projection the central ray is also directed precisely between the feet but at the level of the malleoli If care is exercised, surprisingly little forefoot overlap will be recorded.

The full-foot radiograph should not be performed as a diagnostic radiograph *per se* It is used primarily as a radiographic pattern for foot appliance construction (orthopedic modification of shoes, and design of custom shoes), and as a recording medium for dynamic foot-imprint radiographs The full-foot radiograph may be recorded on either x-ray film or x-ray paper. In appliance work the paper radiograph has two advantages. it may be visualized directly without the need for transillumination and it may be easily marked with appropriate designations. The full-foot radiograph is made as a supplementary chart following the conventional lateral and dorso-plantar projections of each foot on separate films

This full-foot view is accurate in respect to foot size because two exposures are used to create the image (Fig. 339). In each exposure the central ray is directed in such a manner as to create accurate image size (Fig. 340) Furthermore, the point of contact of the flesh is sharply delineated upon the film when the divergent ray meets it precisely. This contact outline is more accurate than a pencil contact that would be held away from the film by the thickness of the wood to the lead

In any lateral view of the entire foot, there is always an over-all magnification of foot size because the divergent rays extend the foot at each end (Fig 341). The parts adjacent to the central ray are most accurate in size.

These explanations are made because, in the comparison of a lateral view of

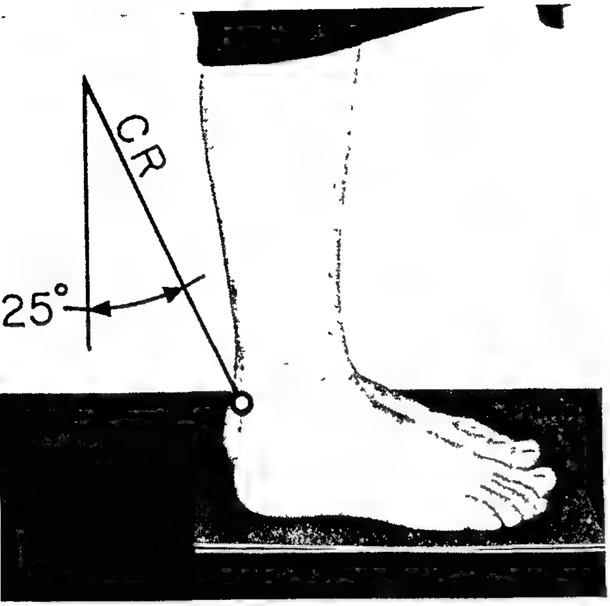


Fig 335 Postero-plantar Calcaneus Projection.

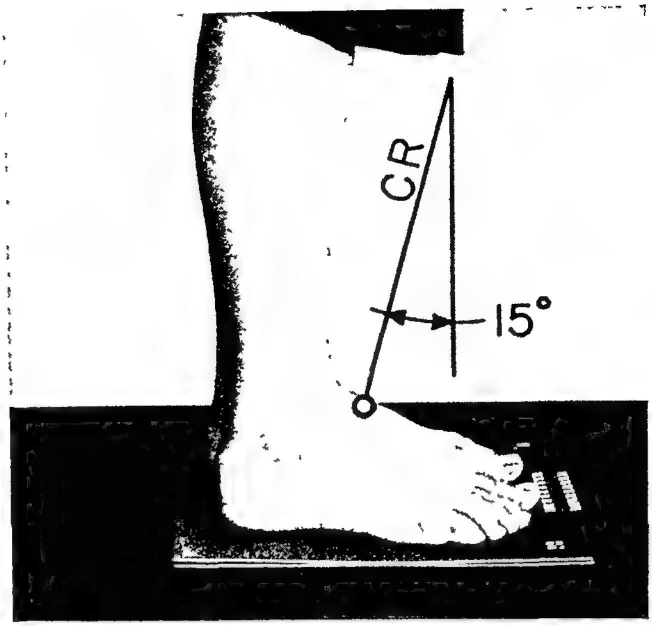


Fig 336 Dorso-plantar Foot Projection.

Fig 337. Postero-plantar Calcaneus Radiograph Note the incompletely exposed portion of film in the anterior region of the foot.

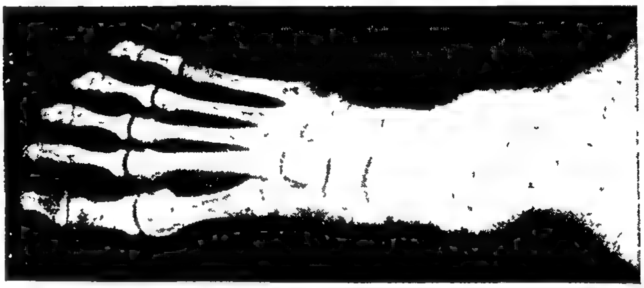


Fig 338 Dorso-plantar Foot Radiograph. Note the incompletely exposed portion of film in the heel region

Fig 339. Composite Dorso-plantar and Postero-plantar Radiographs. The same foot projected on one film Patient immobile as tube is moved and two projections are superimposed Make the dorso-plantar first, then the postero-plantar

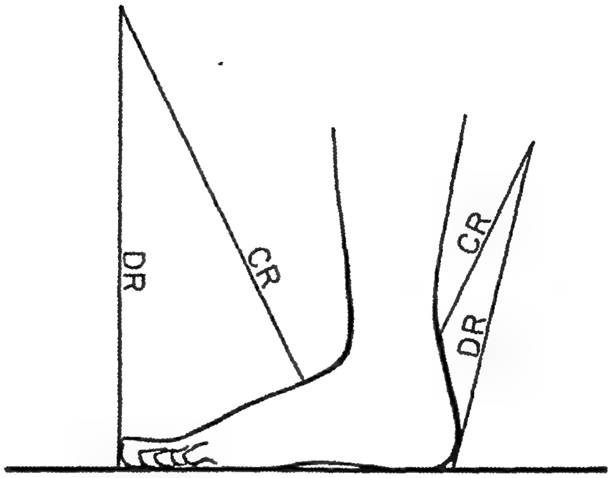


FIG. 340. ACCURATE COMPOSITE FULL-FOOT RADIOGRAPH. Made from two projections with flesh contact delineated by each exposure.

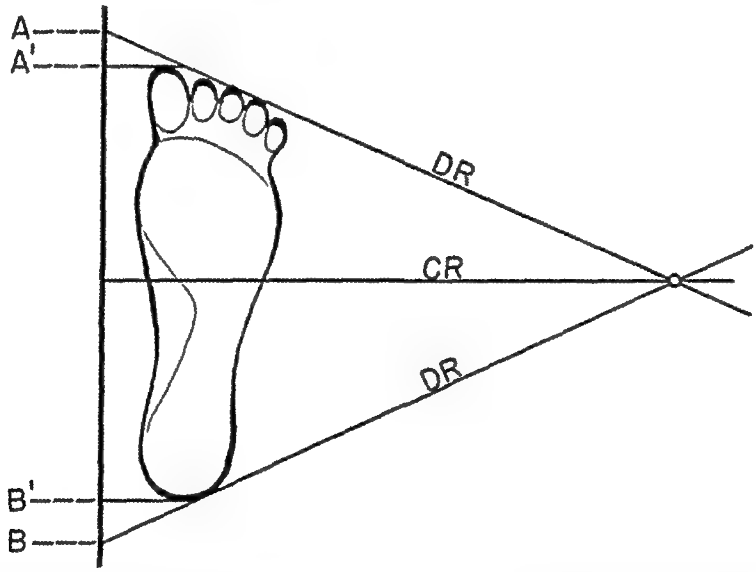


FIG. 341 SLIGHT ENLARGEMENT OF LATERAL FOOT RADIOGRAPH. Made with a single projection because of the geometric extension of the image (A–A' and B–B') by the divergence of the ray.

the foot with a full foot radiograph, it is readily noted that the lateral view is larger than the full-foot view. The latter is correct in size from the flesh outline of the tip of the great toe to the flesh outline at the back of the heel

A similar technique is described by Cahoon with knee bent in postero-plantar projection.

ORTHODYNAMIC WEIGHT-DISTRIBUTION, FOOT-IMPRINT RADIOGRAPH

The result of this new technique of radiographs, upon which are imprinted a weight-distribution graph depicting the forces developed in the completion of gait, represents a unique dynamic departure from the standard foot radiograph which portrays only the static condition of the structure (Fig. 342).

FIG 342 ORTHODYNAMIC WEIGHT-DISTRIBUTION FOOT-IMPRINT RADIOGRAPH

Accurate correlation of the dynamic foot imprint with the radiographic visualization of foot structure will revise concepts that have been necessarily accepted on presumptive evidence. It will be noted from its use that the major part of the weight is not necessarily transferred over the longest metatarsal segment. The importance of toe participation will become apparent. New facts concerning foot function will become a matter of a record that may be easily achieved by a simple office procedure.

Harris and Beath have developed means for imprinting which consist of a rubber mat molded with a gridlike pattern of varying density in order that large squares are shown where light weight reaches the recording and smaller squares are shown where heavier degrees of weight distribution are provided. This foot imprint method is used in achieving the dynamic weight-distribution, foot-imprint radiograph

In order to be dynamic the foot imprint must be executed in such a manner that it will depict both the surface weight and the resistive surface reactions that take place in body progression, weight support, and propulsion. For practical purposes this may be done by having the patient stand a pace away from the recording mat, slowly advance the foot in stride, step upon the recording surface and pause there momentarily, and complete the step by taking off with the initiation of normal stride. Such a procedure would supply data concerning three phases of study in one imprint

(1) The contact areas that develop when the foot first strikes upon the heel are shown.

(2) The impress of full body weight while standing is depicted.

(3) Also given are the imprint reactions of the flow of weight through the foot, including the specific stresses involved in raising the weight of the body upon the metatarso-phalangeal articulations and the pressures developed by the toes in propelling the body forward.

Radiographic Weight-Imprint Technique. The object of this technique is to superimpose simultaneously the foot imprint upon the sensitized emulsion of the x-ray paper or film with the x-ray exposure of the foot. The radiograph utilizes the full-foot technique.

Materials Needed and Their Preparation. The following items must be ready for use before the procedure is initiated:

(1) Two flexible plastic film holders, 10 in. x 12 in. (General Electric X-Ray Corp.).

(2) Two Harris and Beath impression mats. The mats should be cut to 12 in in length to fit the film-holder.

(3) A bottle of stamp-pad ink.

(4) A roller—this will first be used to apply the ink to a piece of glass as a reservoir to ink the roller smoothly. Later it will be used to ink the Harris and Beath mat.

(5) A supply of x-ray paper or film, 10 in. x 12 in. This will be needed for the exposures.

Preparation for the Imprint and Radiographic Exposure. The following steps must be carried out just before starting the procedure:

(1) Ink the impression mat by transferring ink from the glass-plate reservoir with the roller. Use long firm strokes and avoid over-inking in any one spot.

(2) Open the flexible film-holder and lay the impression mat in the center, using forceps to handle the inked mat.

(3) In the darkroom, with safe-light illumination, carefully place a sheet of x-ray paper or film over the mat. The emulsion side, which is the glossy one, should be toward the mat. The paper will bow away from the mat, but do not press it in contact with the mat Carefully close the envelope

(4) Carefully turn the film-holder so that the tube side is upward, carry it to the x-ray stage, and place it on the floor in such a manner that there will be room for the x-ray tube to by-pass the patient when he is standing with one foot in the center of the mat and the other foot alongside it.

Making the X-Ray Exposures and Guiding the Patient Through the Phases of Gait to Record the Dynamic Imprint As each foot will be exposed separately, two exposure holders, each loaded with an inked mat such as just described, should be available so that the exposures may be carried through expediently.

Before taking the patient to the x-ray room, the doctor should show the patient a foot-imprint radiograph so that the patient may be aware of the need for care during the actual recording process Everything should be in readiness when the patient is admitted to the x-ray room The doctor should demonstrate every step of the procedure to the patient before instituting the actual exposure

Steps in the procedure are as follows·

(1) Everything is in readiness, with the loaded exposure holder on the floor in front of the x-ray unit with room for the tube to by-pass the patient in both front and back views

(2) The patient stands a short pace away from the exposure holder. With a natural step, he reaches forward and places his foot in the center of the holder Then he brings the other foot alongside and stands still in this position for the x-ray exposures.

(3) The operator brings the tube into position and makes a dorso-plantar exposure along the long axis of the foot. He then moves the tube past the patient and makes the supero-plantar heel exposure. The tube is now in back of the patient

(4) The patient is instructed to step forward off the exposure holder, starting with the indifferent foot.

(5) The procedure is repeated for the other foot.

Note: The technique is performed with the exposure holder on the floor, as it would not be feasible to have the patient carry through a natural stride up, on, and off an elevated platform.

Exposure Data and Processing Instructions. For the average medium-sized foot, the exposure data for x-ray paper are as follows: 55 Kv. P.; 10 Ma.; 24 in.; 3 sec. The time factor listed is half that of the normal exposure rating for x-ray paper To compensate for the short exposure time, which speeds up the technique, the developing time should be doubled when the x-ray paper is processed.

The exposure holder should be unloaded carefully. The x-ray paper should be peeled away from the mat; then, the mat may be lifted from the exposure holder with forceps and stored in an appropriate place.

The x-ray paper should be clipped in the film hanger in the conventional manner and processed as usual X-ray paper should be developed according to a time and temperature chart devised for screen x-ray film. Comment: Correlation of weight distribution according to the reactions of gait upon the actual radiograph of the osseous structures provides a very significant instrument for study. Since it is recorded upon a direct-reading negative and the graph is clearly apparent, it is convenient to visualize and to use in charting foot imbalance and in appliance design.

STEREOSCOPY OF THE WEIGHT-BEARING FOOT

In the process of viewing conventional foot radiographs, the examiner is confronted by the fact that he is dealing with an image depicting bones that does not convey a three-dimensional effect, such as would be observed in viewing a foot skeleton. Rather, the conventional radiograph superimposes one structure upon another into summations of density, which the skilled observer interprets on the basis of experience into a haphazard concept of three dimensions There is, however, much supposition involved

Actually, only two dimensions of a radiographed object may be visualized—height and width The third dimension, depth, is not present As a result of this well-known fact, it is standard practice to radiograph any object from two divergent planes of exposure so that all three dimensions may be appraised individually from the two films

Instantaneous visualization of the three dimensions of the foot bones may be achieved by stereoradiography. Stereoscopy of the weight-bearing foot not only produces three-dimensional visualization of the bones, but it also shows their spatial relationship to each other from the standpoint of anatomical alignment. Thus, depression of the longitudinal arches may be appraised on the basis of specific fault. The foot bones appear as a standing skeleton, as seen in the radiographic visualization

Under normal circumstances everyone utilizes stereopsis to gain three-dimensional vision. The left eye views an object from a slightly left-sided angle, while the right eye views the same object from a slightly right-sided angle. Each eye receives a two-dimensional image upon the receptive area of the retina, known as the fovea, which in turn transmits the image to the brain. The brain, in turn, fuses the two images together by superimposing each view to produce a three-dimensional concept as a single visual impression.

The same situation normally developed by binocular vision, which we have just discussed, may be artificially produced through either photographic recording or radiographic recording. Both systems are viewed through a device known as the stereoscope. The radiographic system will be explained

Two radiographic images of the foot must be produced. The first is made by radiographing with the central ray directed slightly from the left side. The second image is radiographed with the central ray directed slightly from the right side. In each case the central ray is moved left and right from the normal centering position. These radiographic views correspond to those that would be observed by each eye. A stereoscope is utilized to view the radiographs after they have been produced. In principle, the stereoscope is a device that isolates the eyes, thus allowing each eye to view the appropriate view and transmit the images to the brain on an individual basis There the images are superimposed to give the concept of depth.

The application of the principles of stereoscopy to skiagraphy or radiography was first employed in this country by Professor Elihu Thompson in 1896, the year the x-ray was discovered Thus the art is very old, but the application of stereoscopy to the weight-supporting foot to show the alignment changes characteristic with the full stress of body weight is a new development—a new application of an extremely old art.

Stereoradiographic Technique. In order to achieve the necessary views, the two views must be standardized very precisely, so they may accurately superimpose when they are processed and placed in the stereoscope for viewing It is imperative to use the Ortho-x-poser in order to produce natural posed radiographs of absolute standardization for a stereographic pair. Along the opening of the film-well a one in scale is provided for the purpose of realigning the film-holder to insure accuracy in this technique.

The patient is posed for a standard, lateral view of the foot The position of the film-holder in reference to the one in scale is noted. The central ray is properly aligned Since the cone of the x-ray tube touches the end of the Ortho-x-poser, a chalk mark is made at the exact cone center to indicate the normal exposure alignment

At a distance of 24 in, the tube shift should be one-tenth of this film-tube anode distance, or 2 4 in. This shift must be equidistant from the centering line; consequently, we must measure 1 2 in to the left of the chalk-line norm for the first, or left eye, view We make a chalk mark there. Then we measure 1 2 in. to the right of the chalk-line norm and make a mark for the second, or right eye, view Following this marking the exposures may be initiated at once.

The first exposure is made for the left view, and the film is marked with an "L" stereo marker. Following this exposure, the film-holder is removed and the second film-holder is inserted in the position already noted for the first exposure. The second exposure is made following the tube shift to the right position and the film is marked with an "R" stereo marker. This completes the pair of stereoradiographs (Fig. 343).

When using the Ortho-x-poser we may, as a matter of expedience, use one film in the film-well. The first view of the stereoscopic pair is taken on the upper half of the film The film-holder is then removed and the film reversed in the well so that the second view may be completed on the other half of the film. After processing, the film is cut in half to provide the separate stereoscopic pair to be placed in the viewing device. This method is given since it provides film economy and saves time during the processing technique.

Stereoradiographic Viewing. There are several optical systems that may be employed for stereoradiographic viewing. Gass and Hatcher have reported a simple method in which the radiographs are placed side-by-side in perfect alignment in the view box, and a 20-diopter prism is held in front of each eye while viewing at a distance of approximately 24 in. A clear stereoscopic image will be produced in the center of the field, and a blurred image will be visible on each side. General Electric X-Ray Corporation has produced a hand-held viewing device, utilizing mirrors, for viewing a stereo pair of radiographs placed side by side in the view box.

Chamberlain *et al* have devised a fixed optical system known as the Stanford Stereoscope which employs mirrors and special illumination. This device does not require any adjustment, because the radiographs are placed in the proper position and the stereo effect is visualized as one image of three-dimensional scope.

The earliest type of stereoradiographic viewing device employed the Wheatstone principle, in which two separate view boxes were arranged so that a reflection of each radiograph could be picked up by isolated mirrors for each eye. This type of apparatus is cumbersome and utilizes too much office space. The system does illustrate the viewing technique (Fig. 344).

In stereoscopic viewing the visual acuity of the observer is a factor. In instances of poor accommodation to convergence it is very difficult to break fusion and create the stereoscopic impression. Carpentier examined 16 physicians to determine their stereoscopic depth perception and found that ten had adequate depth perception, three had little appreciation of stereopsis but acquired it after short practice, and three did not improve with short practice.

Evaluation The main advantage of stereoscopy is that it provides third-dimensional visualization. The scope of this in radiography is far greater than can be conceived in any photographic sense because of the phenomenal images obtained by the roentgen ray. For instance, the trabecular pattern of the calcaneus is visualized as filling the cortical shell of the bone. The shape and true location of bone cysts and foreign bodies within the bones is dramatically visualized. Spatial relationships of supernumerary bones, fractured fragments, and anatomical pathology are given in a true sense

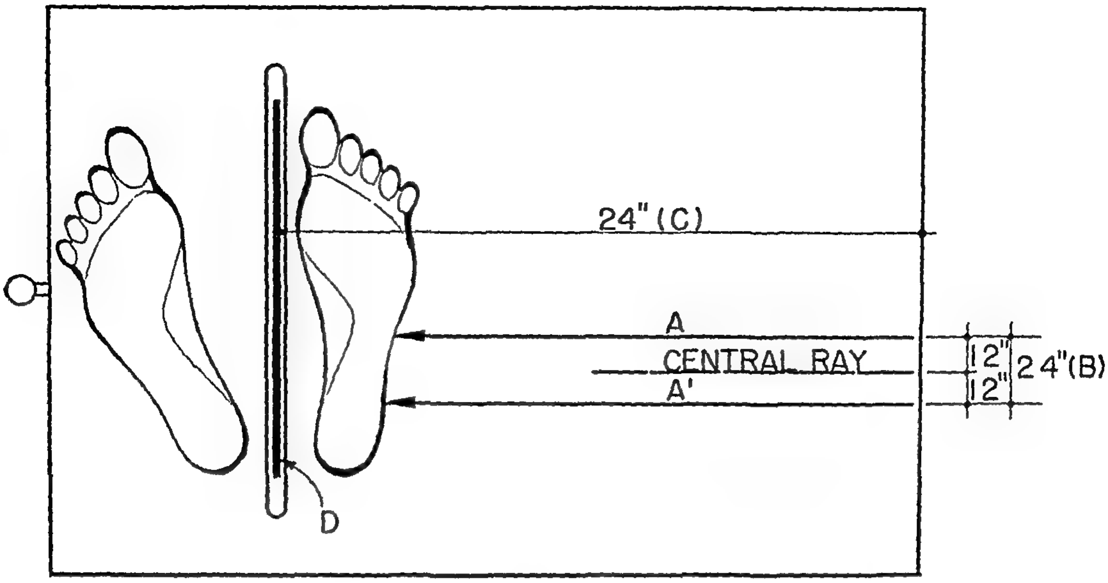


FIG. 343 STEREORADIOGRAPHIC TECHNIQUE (A) Exposure of right view of stereoscopic pair (A') Exposure for left view of stereoscopic pair (B) Total tube shift 24 in, divided equally from normal centering point. (C) Film-anode distance 24 in (D) Film placement precisely the same for both views of the stereoscopic pair.

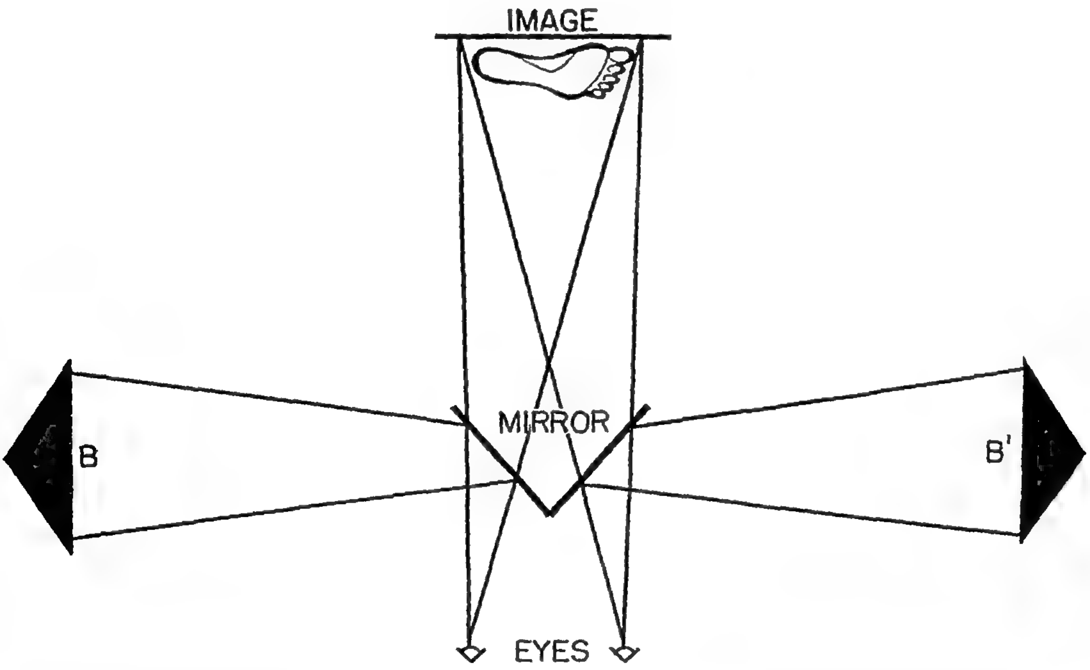
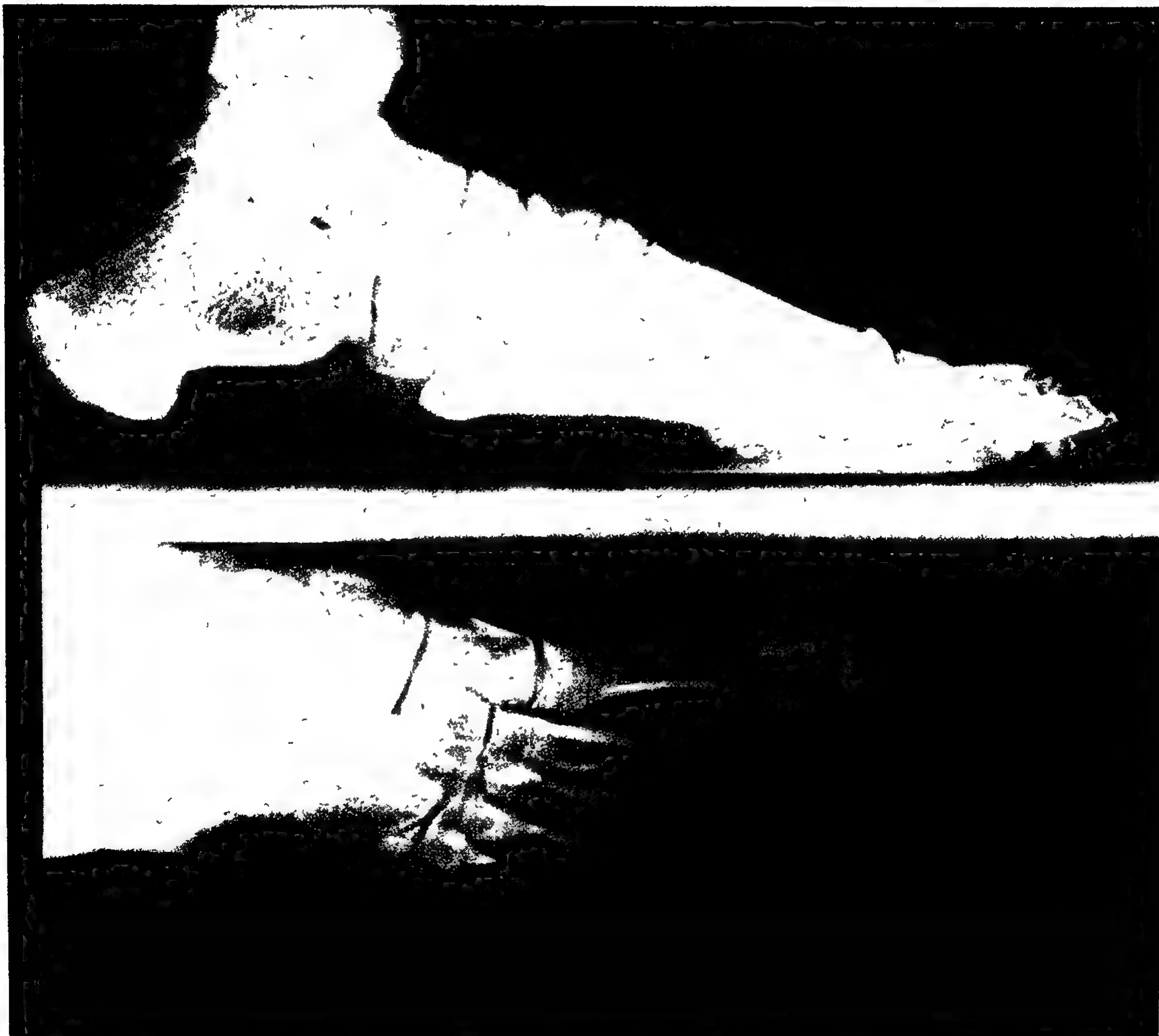


FIG 344 STEREOSCOPIC VIEWING (WHEATSTONE PRINCIPLE) (B) Radiograph illuminated for left eye (B') Radiograph illuminated for right eye

Several investigators have developed the critical phases of technique Klein, Klein, Klein and Newman insist that shadow displacement should *not* exceed three-eighths of an inch Other researchers insist that a distance of 72 in is the best film-tube anode distance. It is universally agreed that the direction of tube shift should cross the long axis of the structures whose radiographic visualiza-



Color Plate—Color-toned Foot Radiograph

tion is desired; hence, in mid-tarsal joint studies the tube is moved as described in the preceding technique rather than up and down.

RADIOGRAPHS IN COLOR

The use of color in connection with radiographs has intrigued investigators in diversified areas. The simplest method of achieving a colored radiographic visualization is to transilluminate it with colored light. This is common practice in many hospitals In some instances the color is used to gain greater intensity, such as that achieved by the yellow-green illumination. In other instances, such as when rose is used, the purpose is to make radiographic viewing less tiring.

Austin has used color for illumination so that 35 mm. photographic transparencies of radiographs might be achieved on the comparatively grainless kodachrome film. These reproductions are excellent.

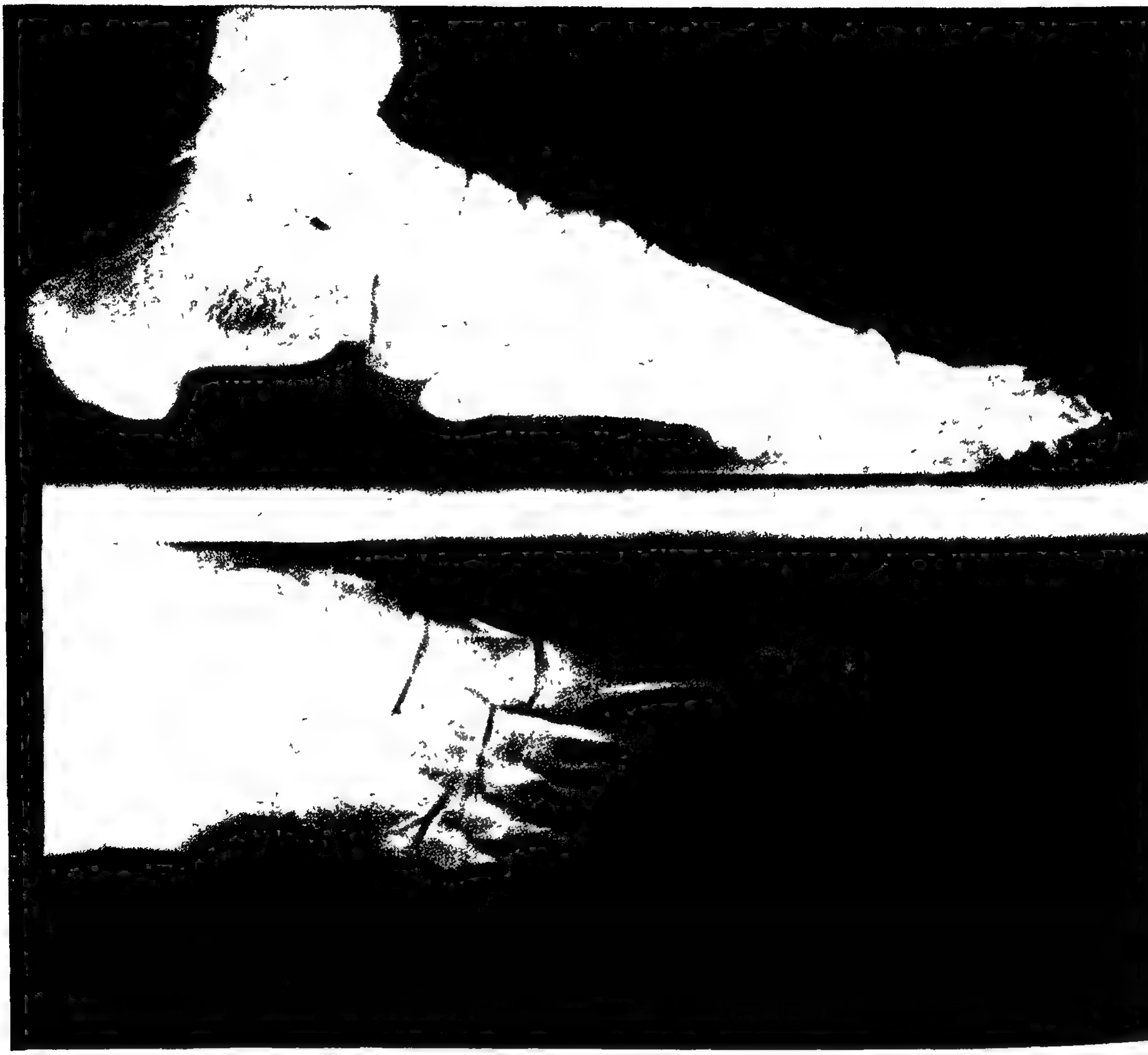
Roentgenography of soft tissues by monochromatic roentgen radiation and color-forming developers was performed by De Carvajal-Forero and Thompson in an effort to gain better visualization of differentiated soft tissues. Their method utilized a 5 mm aluminum filter to gain a long range of gradation of density on the radiograph in order to eliminate the long wave-length rays that cause scattered radiation and subsequent fog. Exposure time was increased by 25 per cent, with all other factors remaining constant. A special-formula developer to produce a dyed blue film was given. The formula is complicated, unstable, and uneconomical to use. The developer has a strong, pungent odor due to the presence of phenacyl chloride which is a tear-gas forming chemical The disadvantages of this method preclude its extended use.

Colored glass pieces are sometimes held before the eyes to achieve a colored perception of the illuminated radiograph. Amber and brown tones are used to heighten the soft-tissue visualization.

Radiographs Toned in Color During experiments directed toward an improved three-dimensional viewing technique, I used an ordinary photographic color-toning formula to produce splendid radiographs in color (Color Plate). Eastman Kodak Company's Formula T11 makes a blue radiograph with uniform results. The technical exposure factors needed for foot radiography, together with the wide-range gradation of density obtained with no-screen films, provided a radiograph suitable for toning when the time of development was reduced 25 per cent. The technique: after development and fixation, the film is washed for 5 minutes and then put in the toning solution until the desired depth of color is reached This is followed by washing for 20 minutes Formula T11 consists of:

	Avoirdupois U S Liquid	Metric
Kodak Potassium Persulfate	7 grains	0 5 gram
Kodak Iron and Ammonium Sulfate (Ferric Alum)	22 grains	1 5 grams
Kodak Oxalic Acid	45 grains	3 0 grams
Kodak Potassium Ferricyanide	15 grains	1 0 gram
Ammonium Alum	75 grains	5 0 grams
*Hydrochloric Acid, dilute solution	¼ dram	1 0 cc
Water to make	32 ounces	1 0 liter

* To make add slowly with stirring 1 part of concentrated hydrochloric acid to 9 parts of water



Color Plate—Color-toned Foot Radiograph

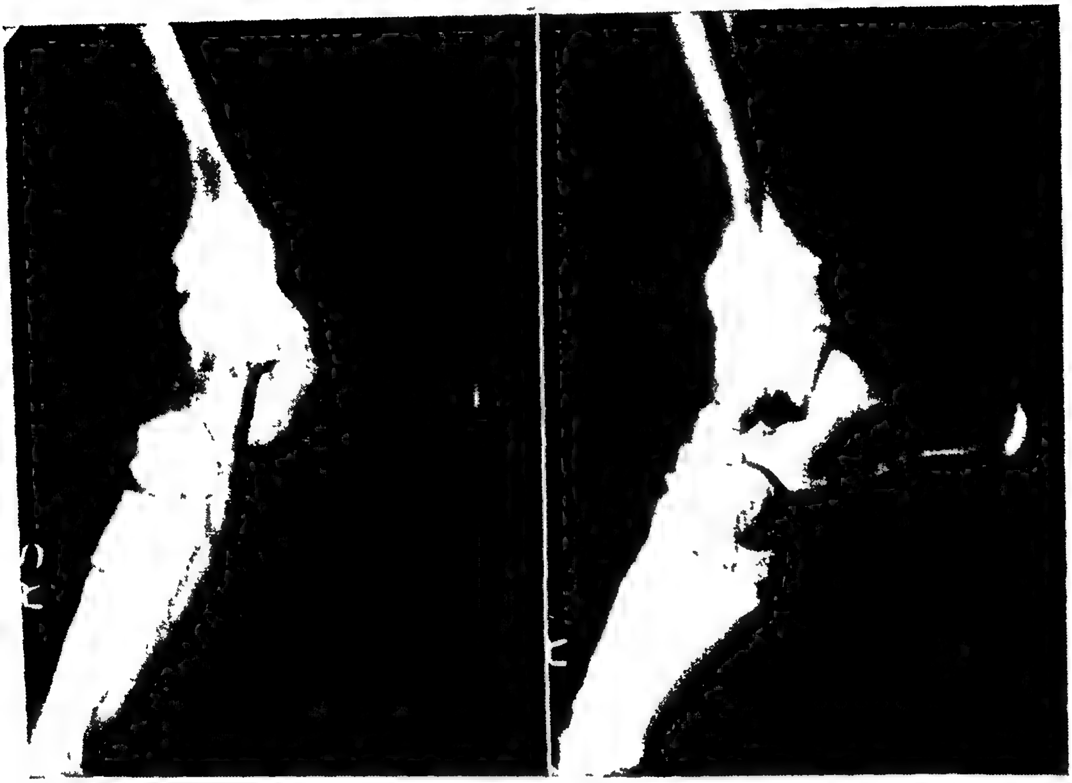


FIG 345 PLANIGRAM. RECUMBENT LATERAL FOOT POSITION. 5 cm level—medial arch segment Note anterior subtalor articulation. 3 cm level—lateral arch segment. Note posterior subtalor articulation Technical factors: Par-speed intensifying screens, 60 Ma, 1½ sec, 43 Kv, 36 in

FIG 346 PLANIGRAM RECUMBENT DORSO-PLANTAR (MID-TARSAL) FOOT POSITION 8 cm. level—medial arch segment and talo-navicular articulation 3 cm level—lateral arch segment and calcaneo-cuboid articulation Technical factors· Par-speed intensifying screens, 60 Ma, 1½ sec, 49 Kv., 36 in.

Dissolve each of the solid chemicals separately in a little water. Mix in the order given, and dilute to volume Both should be clear and pale yellow in color

Evaluation Toning of a radiograph is, in reality, an extension of the developing process, substituting a chemical reaction that creates a blue density instead of the conventional gradation of grey to black Areas that received no radiation are essentially clear and devoid of color Thus, a radiograph toned by a chemical process is different from a conventional radiograph illuminated by colored light The colored light will color areas that would normally be clear and devoid of color

A different quality of visual reception is created by color. Contrast is graded from clear areas through shades of blue to complete opaqueness The net result is a radiograph of greater tone values. Clear areas are high-lighted by the softness of the blue so that depth concept, which depends on the perspective achieved by the summation of density recording, is more realistic. Likewise, the soft tissues are differentiated better by the subtle gradations of blue A color-toned radiograph is easier to view and creates less eyestrain. This could be a very important advantage to the roentgenologist who must spend hours each day before the illuminator. Finally, color adds life to the radiograph and is pleasing to the eye

FOOT-SECTION RADIOGRAPHS

There are instances when it is highly desirable to radiograph a section of the foot that would be obscured by superimposed images in the conventional radiograph. For example, the position of the head of the talus in relation to the calcaneus, including the sustentaculum tali at the subtalor joint, cannot be visualized in the standard radiograph Lateral view segments at various metatarsal levels would be of great value A sectional view of the calcaneus from an anteroposterior plane would demonstrate any valgus rotation, which is unobtainable in standard radiography.

A planigraph, in which a sectional view may be performed at any desired level is the answer to these problems (Figs 345, 346) Although the science of section radiography has been extensively explored by Keiffer and other investigators, and several methods such as tomography, laminography, etc have been employed, the most adaptable scheme seems to be planigraphy

The principle of planigraphy consists of performing the radiograph with the x-ray tube moving in an arc in one direction while the x-ray film moves in the opposite direction The part remains immobile Both tube and film are connected to the movable arm and the axis upon which it turns is the key to the section being radiographed At this level the section is stationary, consequently, it produces a detailed radiograph, whereas all other parts are blurred as a result of the motion of the tube and film (Fig 347)

The apparatus devised by the author consists of an arm, one end of which is attached to the Ortho-x-poser at section level It extends to the film-holder and engages a carriage to move the film-holder during exposure The other end of the arm is attached to a cradle that receives the tube head which moves in synchronization with the film during the exposure During experimental exposures the tube has been moved manually, but the apparatus will not be commercially feasible until it is automatically powered

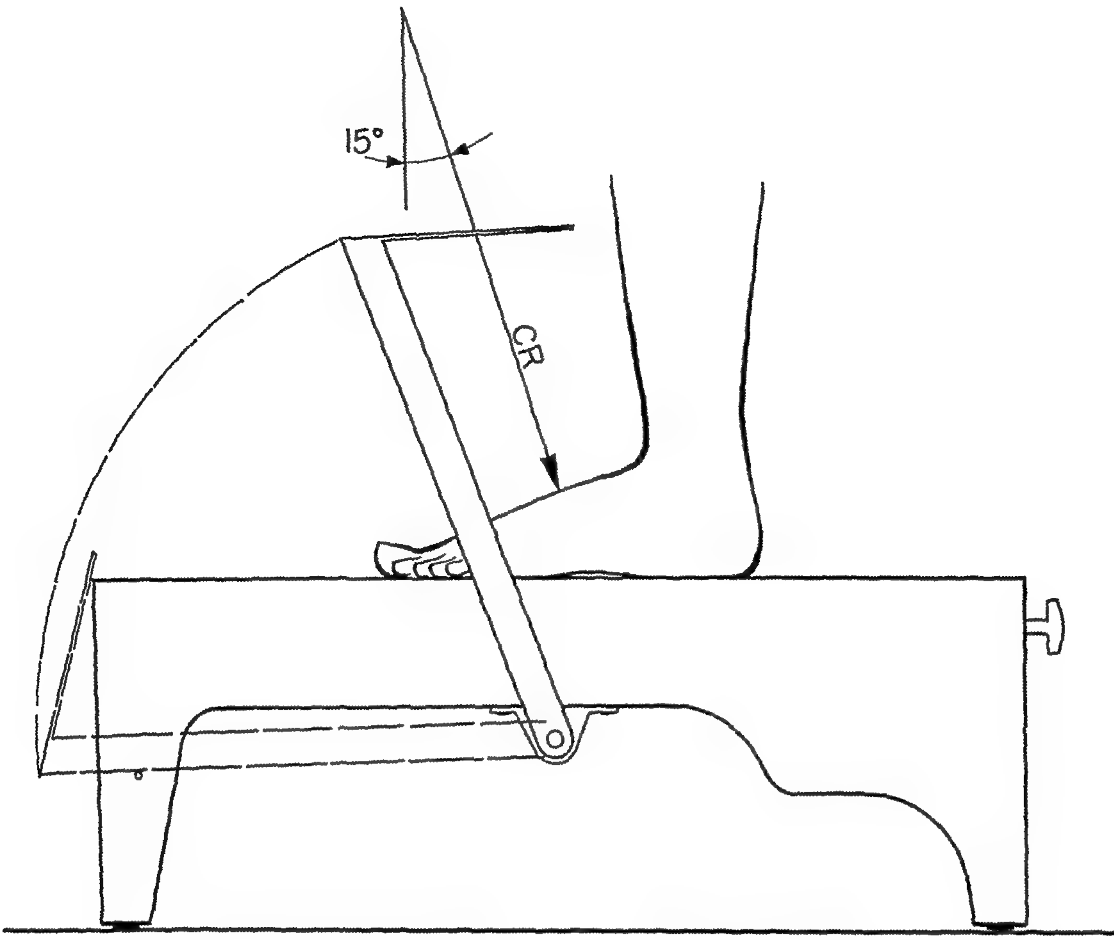


FIG 348 PRINCIPLE OF UNIFORM EXPOSURE DEVICE FOR DORSO-PLANTAR PROJECTION OF THE FOREFOOT When exposure is instituted, the absorption shield simultaneously uncovers the foot, thereby permitting greater exposure to the hindfoot than the toe region

Operation of the device consists of positioning the patient over the exposure holder and raising the absorption shield into position over the entire forefoot After exposure factors are set and the x-ray exposure instituted, the absorption shield is released and allowed to follow a postero-anterior arc, during which it relieves the protection of the part as it describes its downward course. The exposure factors are selected to expose adequately the tarsal region. These factors become effective immediately upon the execution of the exposure, while a shorter milliampere-second factor of the forepart is automatically achieved by the synchronous movement of the shield as it passes through the toe region and off the foot

The radiographic result consists of a balanced radiograph with visualization of the toe region in harmony with the tarsal region (Fig. 349)

Uniform exposure may be simulated without a device by careful positioning technique, although the resulting radiograph falls far short of the uniform exposure obtained by the use of the device. In performing such a radiograph, the central ray must be carried at the proper angle when it is directed at the foot for the dorso-plantar exposure A portion of the x-ray intensity will be lost by the distance that the peripheral ray must cover in reaching the toe area, and thus a nearly balanced exposure is created.

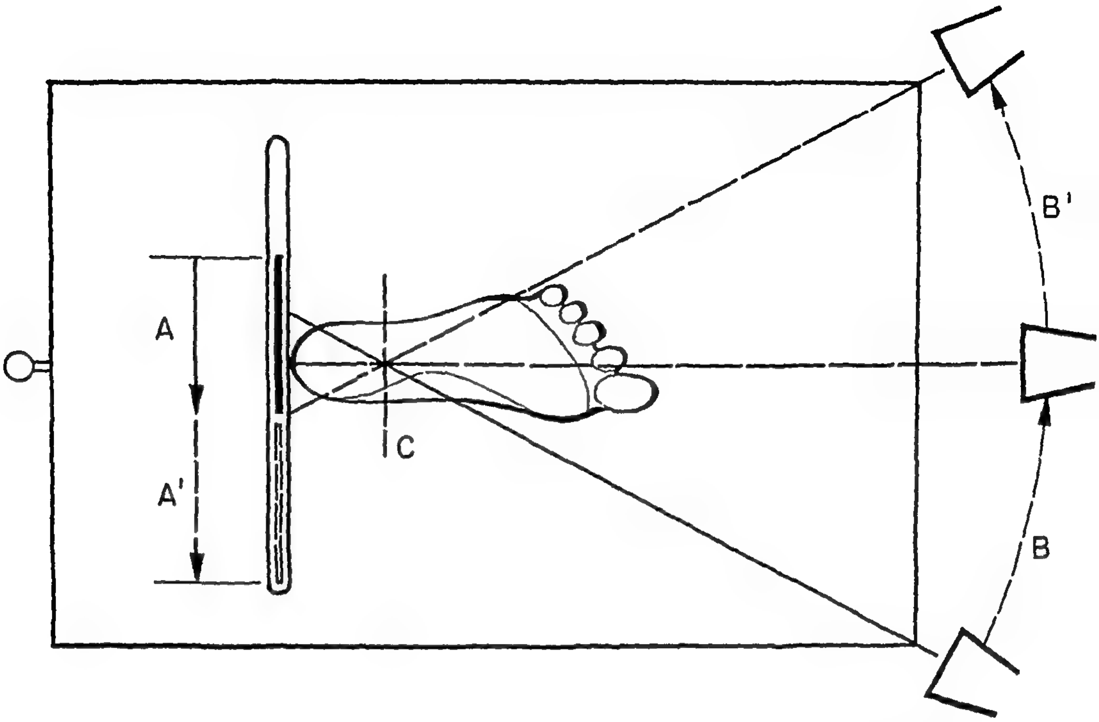


FIG 347 PRINCIPLE OF PLANIGRAPHY (A–A') Film moves in one direction (B–B') Tube moves in opposite direction (C) Film-tube axis remains immobile This plane is radiographed—other parts are blurred because of motion.

UNIFORM RADIOGRAPHIC EXPOSURE OF THE FOREFOOT

It is a well-known fact that, in performing a dorso-plantar radiograph of the forefoot, the toe area is frequently over-exposed when the tarsal area is properly penetrated The variation of the thickness of these two areas is responsible for this situation In addition, the height of the arch is a contributory factor because it varies the distance that the ray must travel to reach the film As a result, a more uniform exposure may be expected in the low-arch foot than in the highly arched one

This problem is an intriguing one, and investigation has disclosed several approaches to the problem, each with certain limitations A filter attached directly to the portal of the x-ray tube was found difficult to control because of the wide variation in foot shape Filters shaped to compensate for the shape of the foot and used directly over the foot created an overclouding lack of contrast in the radiograph due to the added density of the filter A translucent wedge that raised the toe area to the level of the tarsal region, which theoretically should help solve the problem, caused geometric magnification of the toe region and a distortion due to the divergence of the x-ray beam

In order to overcome the basic problem presented, a device was made to control the amount of radiation reaching the foot. It consists of a sheet of metallic substance that will absorb x-ray radiation, an over-balance arm arranged on a pivot, a means for releasing this over-balance, and a means for regulating the speed at which the absorbing shield moves through the field of exposure (Fig 348)

FIG 350 SOFT-TISSUE SWELLING CONCURRENT WITH INVERTED NAIL AND SPICULATED TUFT OF DISTAL PHALANX.

FIG 351 DEPTH OF FOREIGN BODY IN SOFT-TISSUE

by radiographic contrast Havey has reported an interesting study of this kind (Fig 352, 353) Local anesthesia was established in the area prior to the injection of the opaque material.

Venography and arteriography are also performed by the aid of an opaque contrast medium injected into the area Exceptional care must be exercised in these techniques The reader is referred to Moore's description of an effective method of venography for more information.

FOOT FLUOROSCOPY

There is seldom a need for fluoroscopy of the foot and its use should be strictly limited to the search for foreign bodies and to the reduction of complicated fractures The use of a hand fluoroscope in a normally lighted room is ill-advised (Fig 354). In order to obtain good fluoroscopic visualization, the operator must take measures to allow his eyes to accommodate to darkness so that the fluoroscopic image will carry enough detail to be diagnostic

Great danger lies in the indiscriminate use of fluoroscopy without adequate protection from radiation At least one foot practitioner has lost fingers as a result of over-exposure in this manner Although it might seem valuable to check the extent of motion in a joint by fluoroscopy, the examination is so transitory that it is difficult to analyze.

The use of fluoroscopic principles in the shoe store "x-ray" machine is a misguided application of a very potent form of radiation The image of the foot bones within the shoe does not provide an accurate check of shoe fit because the soft-tissue outlines of the toes blend with the shoe construction materials so that no contrasting outline is obtained The normal bone outlines create a false sense of roominess due to their normal spatial relationship and not because of the adequate roominess of the shoe. There have been studies

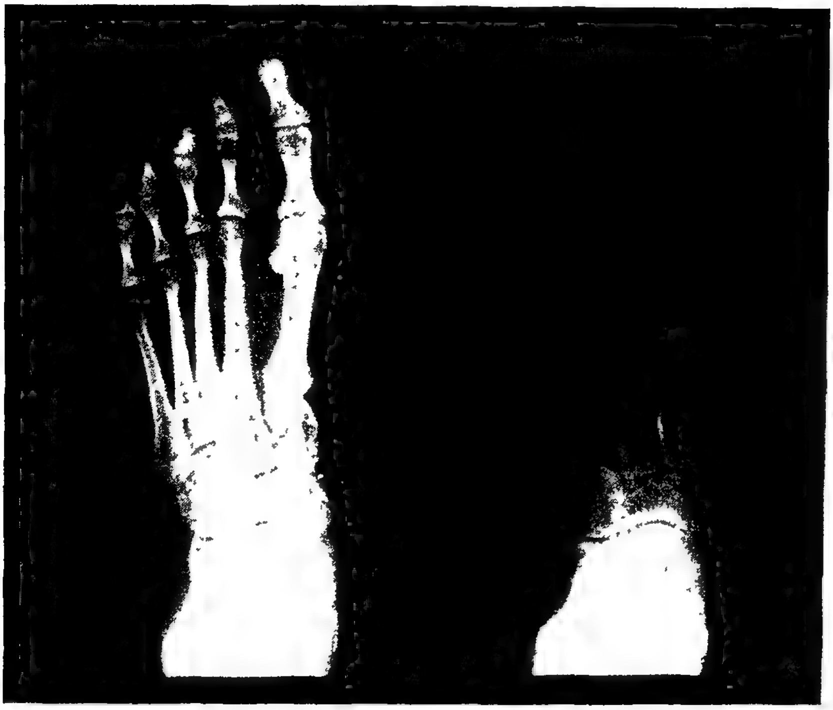


FIG 349 COMPARISON OF UNIFORMLY EXPOSED RADIOGRAPHS Radiograph made with the device, and radiograph made with same exposure factors without the device

SOFT-TISSUE RADIOGRAPHIC TECHNIQUE

The discerning effects of all kinds of swellings, of soft-tissue tumors, of heterotopic calcifications, and of early bone callus, as well as the distinctive characteristics of alterations in fat, muscle, cartilage, and tendon (as visualized radiographically) should warrant more emphasis on exposures that will demonstrate soft tissue (Figs 350, 351). To fully appreciate this medium of diagnosis, the work of Ferguson in interpretation of non-osseous effects, visualized radiographically, should be investigated

Technique The inherent long-scale gradation of density obtained by the use of no-screen x-ray film, used in conjunction with as low a kilovoltage value as will penetrate the soft tissue, will produce maximum contrast of the elements within the soft-tissue density Earlier in this chapter the value of color in soft-tissue work is emphasized.

Use of Radiopaque Contrast Media in Soft-Tissue Radiography Soft-tissue surface detail and foreign body localization have been explored by Barnes and McLachlan, who used a litharge paste consisting of a mixture of lead oxide and nujol at the consistency of facial cream and spread over the skin surface. With low-kilovoltage technique and the film sealed in black paper for a holder, fingerprints and handprints may be performed radiographically, as well as recording of details of the skin surface of the foot. In using this method, foreign bodies may be related to surface skin details for localization

Iodized oil and other similar preparations have been used by injection into cyst and sinus-like areas to delineate the ramifications and shape of the areas

FIG 353 SAME CASE AS FIG 352 LATERAL VIEW
(Courtesy of Dr H. Harvey Numbers)

although pelvic outlines are obtainable with the usual foot radiographic equipment Roentgen exposure of heavy parts creates considerable scattered radiation, which in turn produces blurring of normal radiographic images. This may be controlled by a Potter-Bucky diaphragm, which is a movable grid device that absorbs the scattered radiation, or by the use of a stationary grid of the Lysholm type which serves the same purpose. A vertical cassette holder should be mounted on the wall so that the film may be adjusted to the appropriate positions

In preparing for postural radiographic studies, it is necessary to insure systematically level relationships between the platform upon which the patient stands and the cassette holder When this is established, the patient is posed in natural position, and the radiographs are performed at the desired levels

In addition to demonstrating the relationship of medial rotation of the talus that occurs with medial rotation of the tibia, knee joint relationships, position of the femur, and tilt and level of the pelvis, also the relative leg lengths may be measured Lateral views are necessary for complete evaluations Jones has devoted an entire book to the study of "The Postural Complex."

FIG 352 MULTI-LOCULAR CYST INJECTED WITH 40 PER CENT IODINE IN PEANUT OIL—DORSO-PLANTAR VIEW

performed that indicated that repeated exposure to radiation may have some effect upon growth centers, consequently, there has been some criticism of the use of fluoroscopy for fitting children's shoes The practice of holding the child's feet immobile during exposure is fraught with danger since the same shoe clerk receives repeated radiation

POSTURAL RADIOGRAPHIC STUDIES

The inter-relationship of foot problems to the alignment of the entire lower extremity and its influence on the pelvis may be appreciated when a complete radiographic study is made of foot, ankle, knee, and pelvic region, with the patient in his natural posture Hammond contends that a foot problem may never be completely controlled unless the patient is guided to control of the entire postural problem. The production of postural radiographic studies requires an x-ray generating unit capable of penetrating the sacral region of a heavy individual; consequently, special equipment is needed to do this work,

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FIG 354 ILL-ADVISED USE OF HAND FLUOROSCOPE. Fraught with danger and unsatisfactory radiographic visualization.

Chapter XX

Roentgenographic Clinical Applications

The application of roentgenography to any phase of clinical practice offers an interesting field for study. Clinical research may be a relatively simple form of investigation; however, the doctor who keeps accurate records of simple procedures makes a fine contribution to statistical data that will be useful in developing new and intriguing uses for radiography

A number of clinical projects have been investigated by roentgenographic methods Reference has been made to some of these projects in earlier chapters; however, detailed discussion has been reserved so that attention may be devoted solely to each application. As each project is discussed, a certain amount of background data will be given so that the radiographic approach will be appreciated

The importance of using the orthodynamic weight-distribution radiograph as a diagnostic tool will be evident in the discussion and illustration of a series of cases

Throughout the text a running commentary of clinical considerations has been offered along with the emphasis on interpretation of foot disorders The rehabilitation of a disordered foot is often tedious and many varied methods may be used This is not an indication of confusion, but rather of a choice of therapeutic treatments which may be applied It is the doctor's prerogative to decide the method best suited in any case in question Radiographs performed to demonstrate the results of various methods invariably disclose the interesting observation that *when the treatment is effective,* the anatomical structures are re-established to an improved position approaching normal This is evident in the roentgen visualization of the normal foot, regardless of whether the mode of treatment be adhesive strapping (Figs 355, 356), bi-plane inlay (Figs 357, 358), Whitman brace (Figs 359, 360), contractile muscle stimulation, or shoe wedges and modifications (Figs 361, 362), etc. This approach rationalizes several concepts and suggests restraint in condemnation of an unusual or different regimen. Several methods will be evaluated by radiographic evidence of their effectiveness

The very important Dye technique of flexible casting will be described and illustrated by radiography.

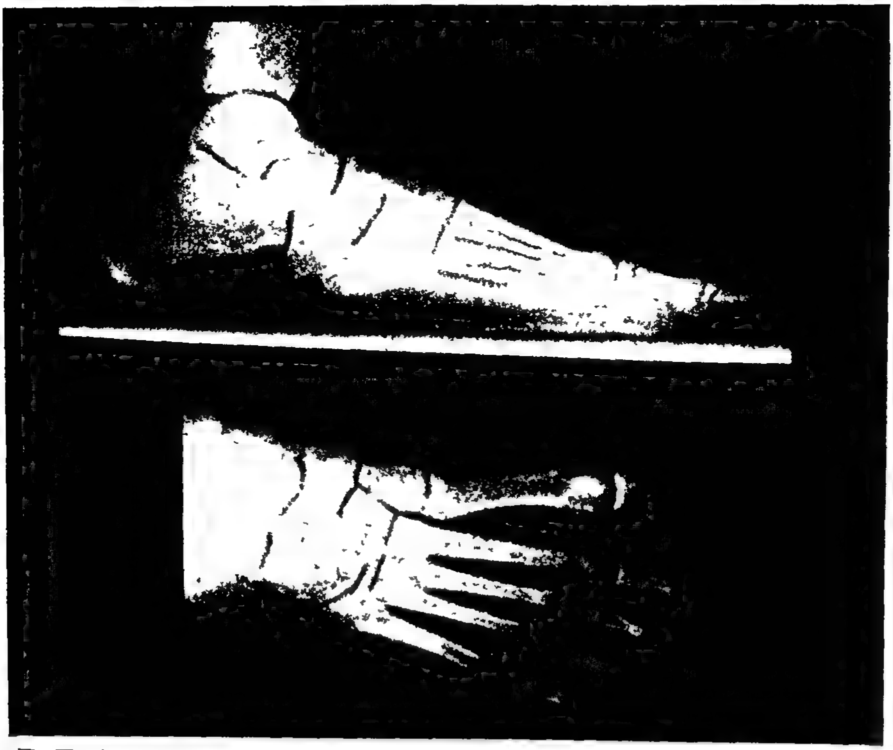


FIG. 357. F. T., MEDIUM MID-TARSAL FAULT—MEDIUM ARCH FOOT TYPE. Note position of talus and altered mid-tarsal joint line.

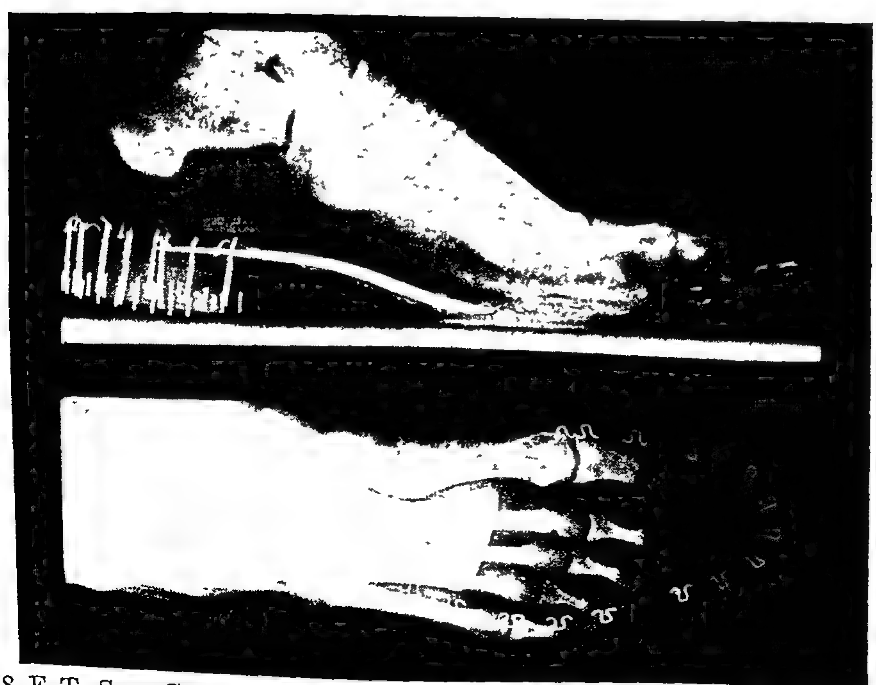


FIG 358 F T, SAME CASE AS FIG 357. Becker bi-plane inlay applied in shoe. Note improved position of talus with visible sinus tarsi and normal mid-tarsal joint.

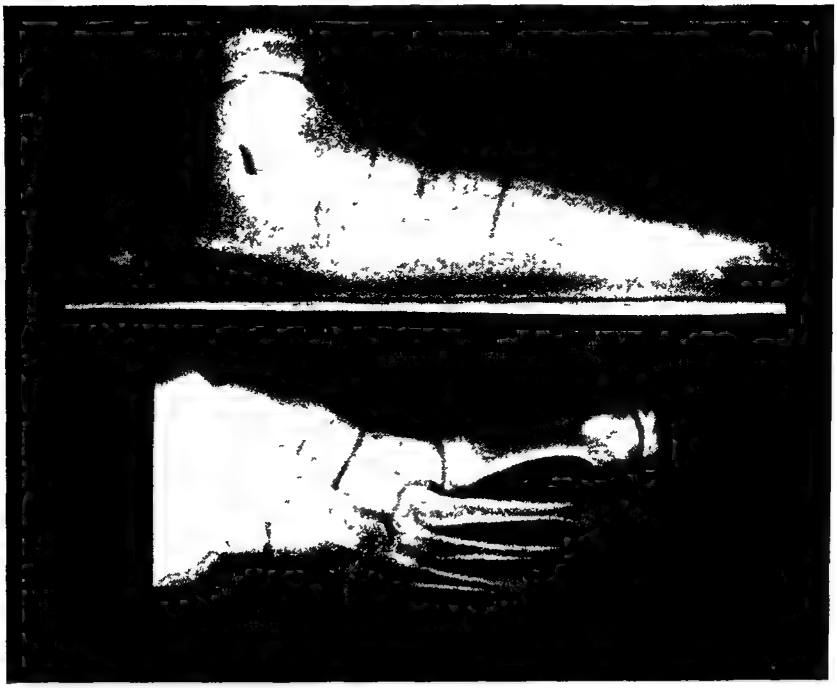


Fig 355 C D, Severe Mid-tarsal Fault—Low Arch Foot Type Note position of talus and closed sinus tarsi

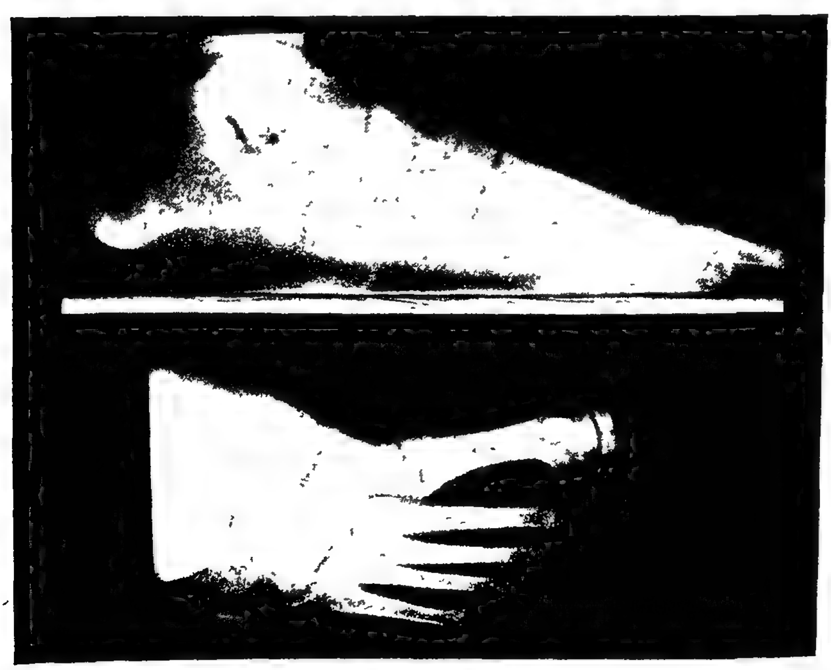


Fig 356 C D, Same Case as Fig 355 High Dye Flexible Casting applied Note improved parallel position of talus, a visible sinus tarsi, and more normal mid-tarsal joint line. The pitch of the calcaneus is higher.

FIG 361. E C., EXTREME MID-TARSAL FAULT—LOW ARCH FOOT TYPE Calcaneus is everted. Note plantar tuberosities Mid-tarsal joint altered and talus mal-posed

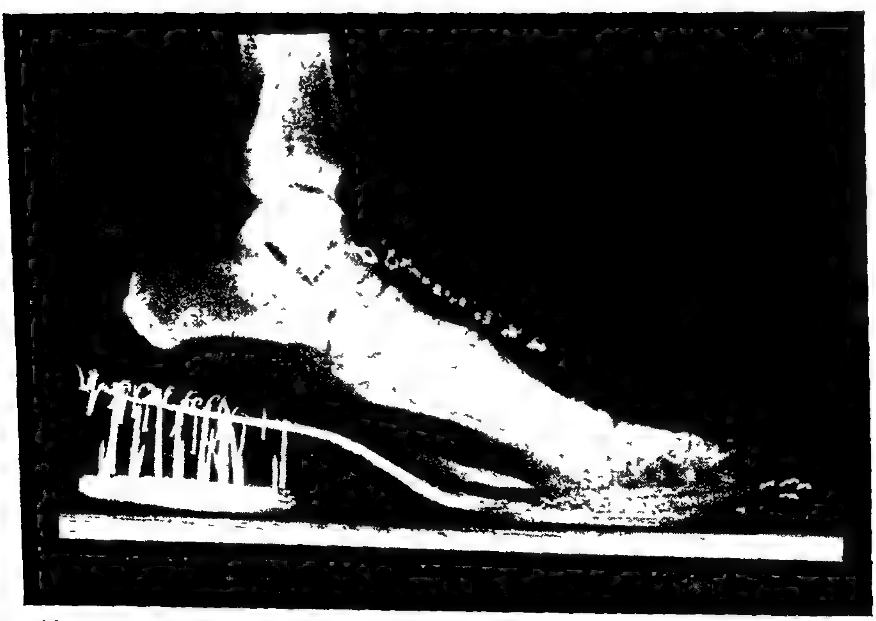


FIG 362 E C, SAME CASE AS FIG 361 Inner-heel extended shoe wedging, medial sole wedging, longitudinal and shank modifications Note improved position of talus and calcaneus Slightly improved mid-tarsal joint.

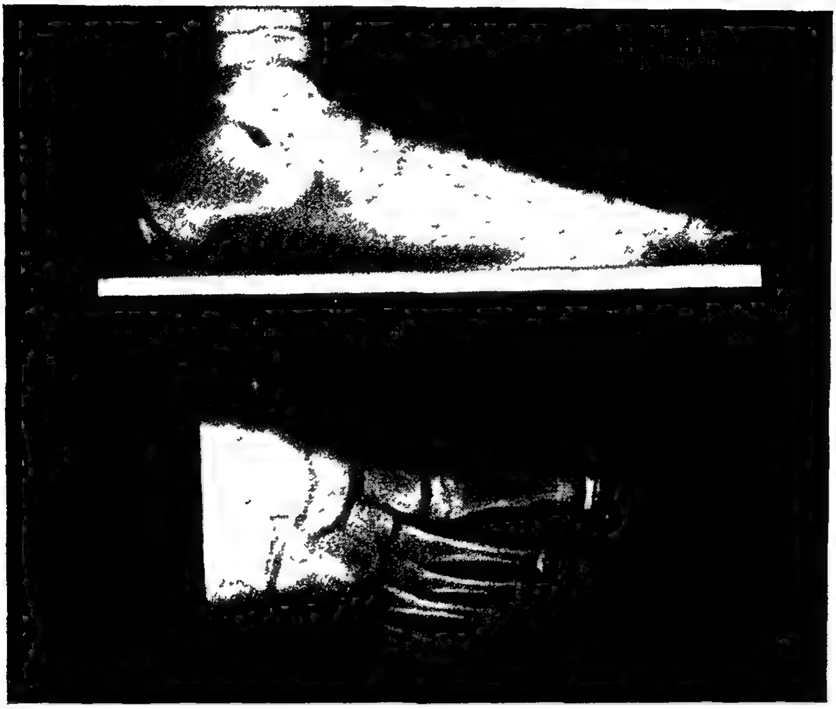


Fig 359 B G, Severe Mid-tarsal Fault—Medium Arch Foot Type Note position of talus and pseudo sinus tarsi

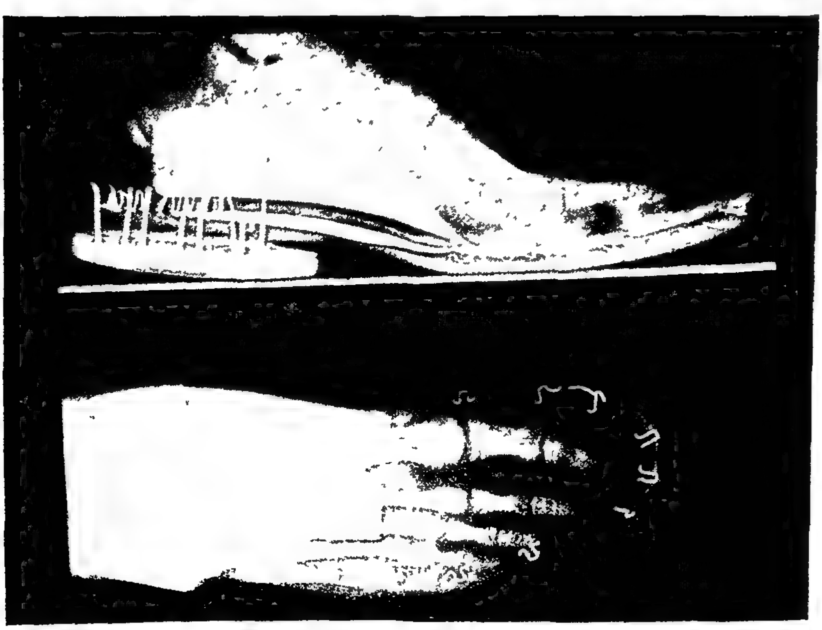


Fig 360. B. G, Same Case as Fig 359 Whitman brace applied in shoe with Thomas heel. Improved position of talus and the sinus tarsi is more visible

FIG 363 ORTHODYNAMIC RADIOGRAPH (X-RAY PAPER) Short first, long second metatarsal pattern. excess imprint to second metatarso-phalangeal joint and inter-phalangeal joint area of great toe.

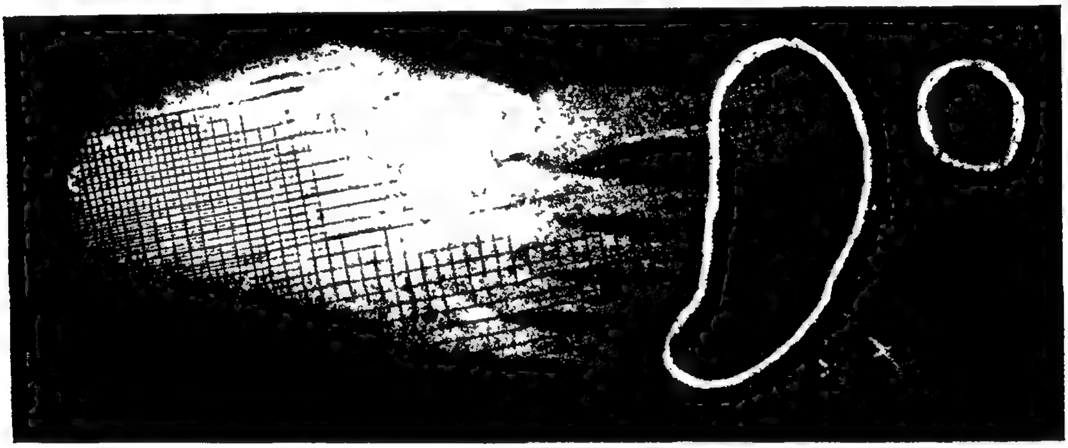


FIG 364 ORTHODYNAMIC RADIOGRAPH (X-RAY PAPER). Lesser toes make little purchase; excess imprint all metatarso-phalangeal joints and distal great toe area.

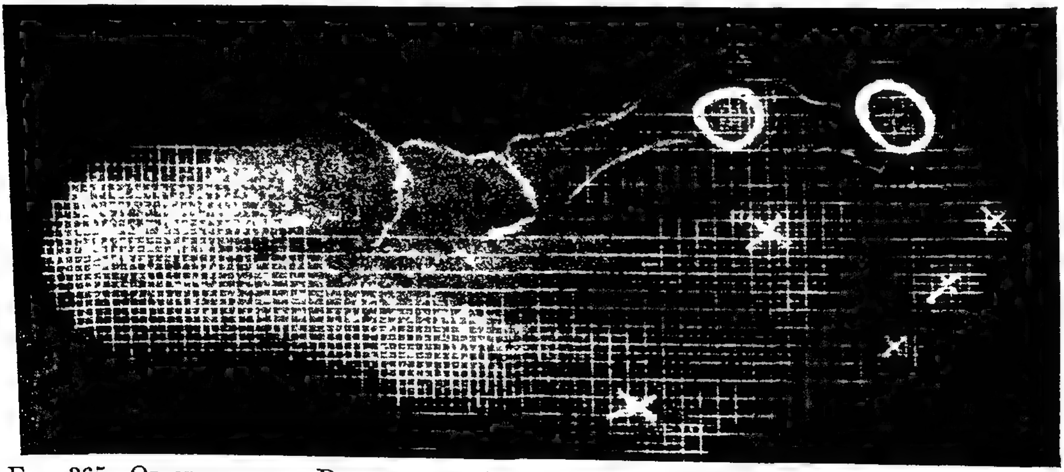


FIG. 365 ORTHODYNAMIC RADIOGRAPH (X-RAY PAPER) Hallux valgus foot type excess imprint to medial sesamoid and inter-phalangeal joint area of great toe.

Extended consideration will be given to the full foot radiograph as a pattern for foot appliance construction.

The orthodigital devices warrant special radiographic consideration. "Before and after" radiographs present mute evidence of their value.

Several problems have been investigated concerning shoes. Radiography helps in assessing features of shoes as they relate to the foot structure Radiographic study of molded shoes should be used to determine their usefulness.

The Brachman splint is of proven merit, and the part that radiography plays in its prescription will be given.

ORTHODYNAMIC WEIGHT DISTRIBUTION RADIOGRAPHS

When the graph of weight distribution is imprinted simultaneously with the exposure of the full-foot radiograph, an interesting clinical record is made The vagaries of the foot which elude the theoretical performances of weight distribution are soon recognized when the doctor employs this diagnostic aid. It becomes apparent that each case must be evaluated on its own merit.

The most striking finding, of which the practitioner is probably aware but is likely to minimize, is the important amount of weight-force carried by the great toe at the inter-phalangeal joint. The amount is increased in cases of a short first metatarsal and a long second metatarsal (Fig. 363). It is also increased when the lesser toes do not participate in weight purchase (Fig. 364). Excessive pressure is recorded on the medial border of the inter-phalangeal joint of the hallux in cases of hallux valgus and in severe mid-tarsal fault with forefoot abduction (Fig 365).

The great toe shirks its normal weight-force load in cases of loss of power of flexion The same situation occurs when the lesser toes are over-active in flexion, thereby relieving some of the normal work of the great toe.

The imprint patterns demonstrated under the metatarsal heads are very interesting As a general rule the long metatarsal members receive the greatest impost, however, strong flexion of the great toe may divert the weight from the long metatarsal member to an adjacent one. A case is shown where an excessively short first metatarsal with an adjacent long second metatarsal exhibited the greatest weight imprint at the head of the third metatarsal (Fig. 119) The same length pattern in the other foot of the case demonstrated weight borne in practically equal amounts by the medial sesamoid under the short first metatarsal, the head of the second and third metatarsals, and the inter-phalangeal joint of the great toe (Fig 366) This demonstration negates Morton's theory, minimizes Henefeld's pivotal action theory, and points up the importance of toe flexion as the regulation factor

Excessive imprint is shown over the metatarsal area whenever the toes shirk weight purchase (Fig 364) This may be the result of simple toe contractions, or pathological problems of rheumatoid arthritis, and other degenerative joint diseases

The inverted foot will demonstrate excessive imprint both on the fifth metatarso-phalangeal area and the great toe area where excessive toe flexion in take-off is present (Fig 367)

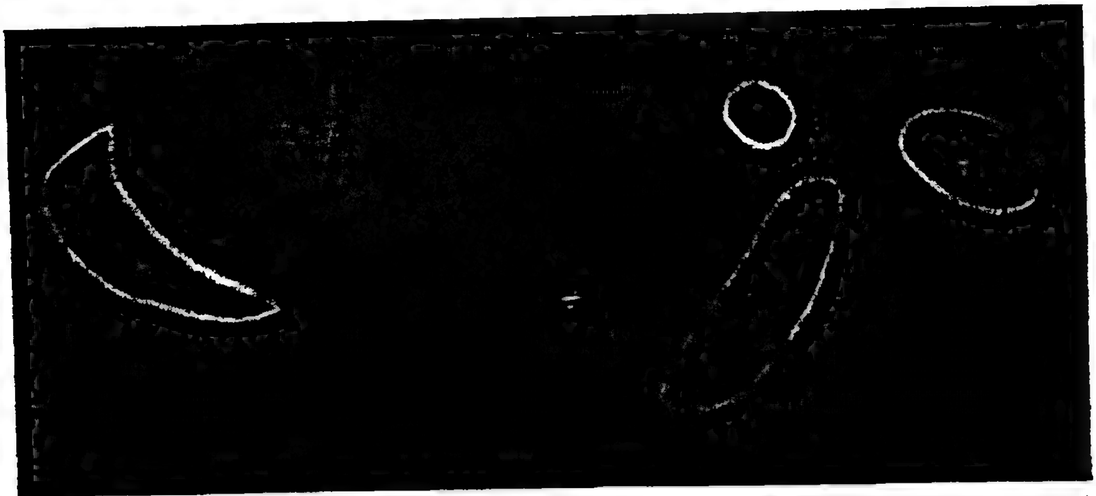


Fig 369 Orthodynamic Radiograph (X-ray Paper) Mid-tarsal fault. excess imprint to medial aspect of inter-phalangeal area of great toe, medial sesamoid; general imprint to metatarso-phalangeal joints, and typical excess by lateral heel border.

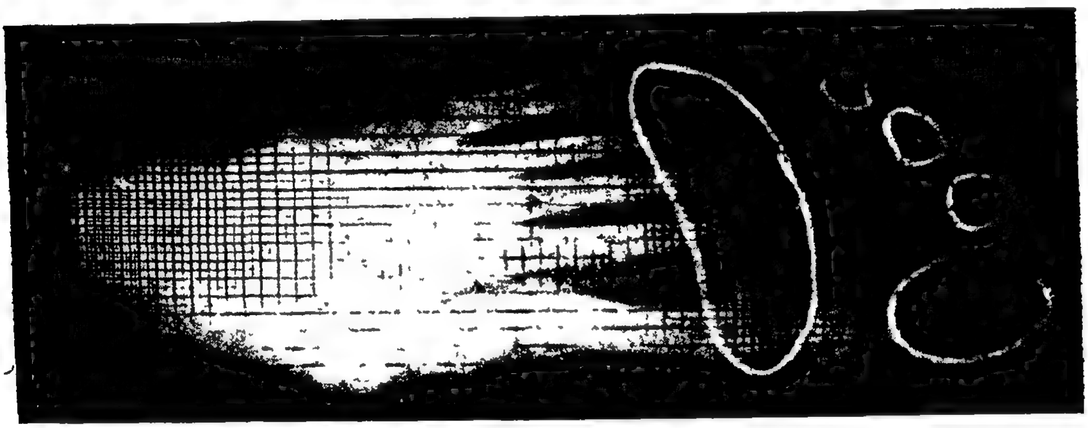


Fig 370 Orthodynamic Radiograph (X-ray Paper). Muscular dystrophy case· imprint for all toes and metatarso-phalangeal joints indicates balancing and propulsive effort

The highly arched foot with normal toe action shows a very typical pattern of little weight distribution in the mid-foot area and excessive amounts under metatarsal heads and under the toes (Fig 368). In pes cavus with toe contractions, the toe imprint is lacking in the above description since the toes do not touch

The total foot imprint in mid-tarsal fault usually demonstrates excessive weight on the medial aspect of the great toe and the medial sesamoid The toe purchase of the lesser toes is linked with the metatarsal condition present There is excess imprint on the outer heel border (Fig 369).

The foot imprint of the muscular dystrophy patient illustrates the benefit of muscle training when excessive imprint is shown for all toes and even distribution throughout all metatarsal heads, because the patient is demonstrating the effect of strong balancing and propulsive muscle effort (Fig. 370).

The malposed foot of polio deformity, resulting from loss of the anterior muscle group, will demonstrate weight impress on the medial cuneiform bone and adjacent articulations.

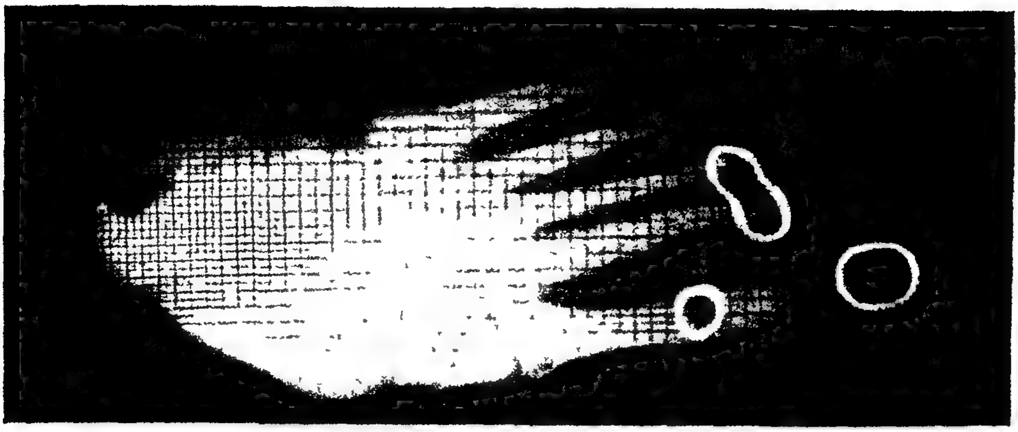


FIG 366 ORTHODYNAMIC RADIOGRAPH (X-RAY PAPER) Short first metatarsal pattern excess imprint to medial sesamoid, second and third metatarso-phalangeal joints, and inter-phalangeal joint area of great toe

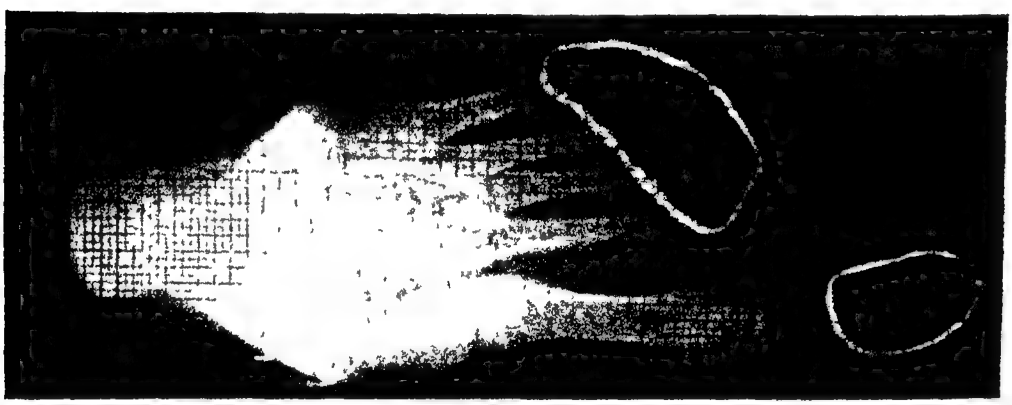


FIG 367 ORTHODYNAMIC RADIOGRAPH (X-RAY PAPER) Mildly inverted foot excessive imprint to lateral metatarso-phalangeal joints and the inter-phalangeal distal area of the great toe

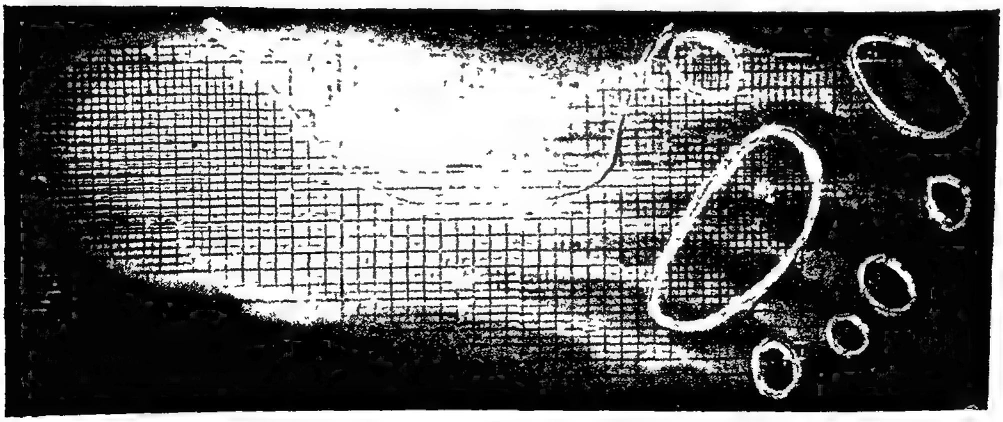
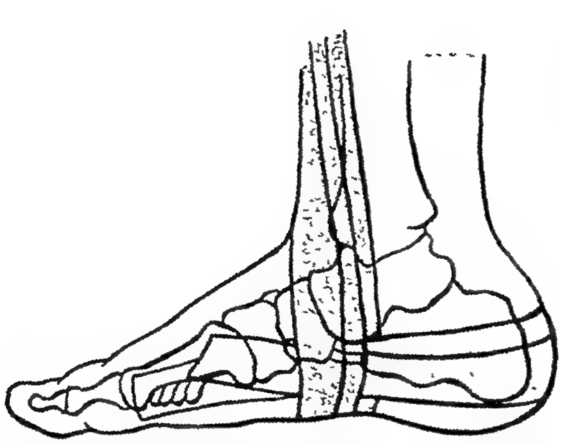


FIG 368 ORTHODYNAMIC RADIOGRAPH (X-RAY PAPER) High arch foot type· excess imprint to metatarso-phalangeal joints, medial sesamoid, and distal areas of toes



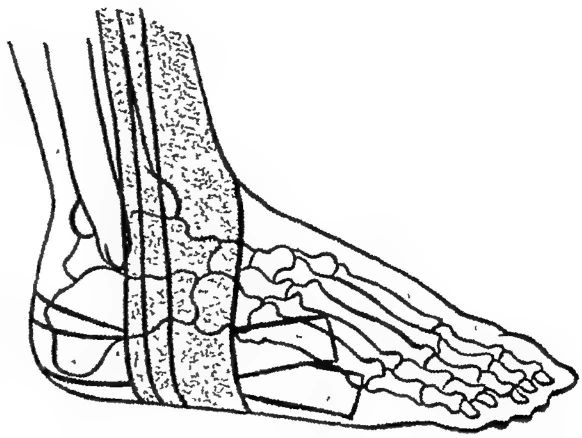
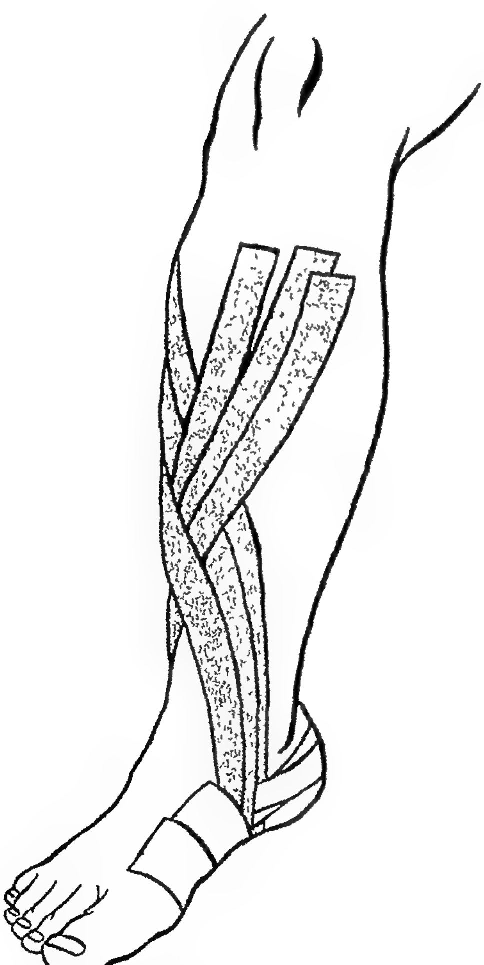


Fig. 373. (Left) Dye Technique. Medial view: Long straps added to aid in support of mid-tarsal constituents, and to stimulate anterior muscle group.

Fig. 374. (Right) Dye Technique. Lateral view: long straps stabilize against excessive inversion and act as mid-tarsal stirrup.



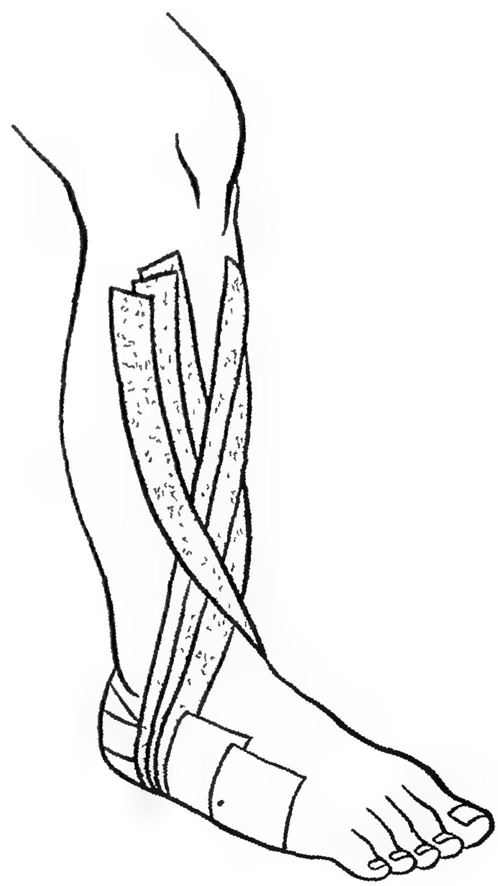


Fig 375. (Left) Dye Technique Medial view. completed flexible casting Course of high tapes crosses high above ankle and never extends to posterior muscle group.

Fig 376. (Right) Dye Technique. Lateral view: completed flexible casting. Medial straps extend to belly of anterior muscle group

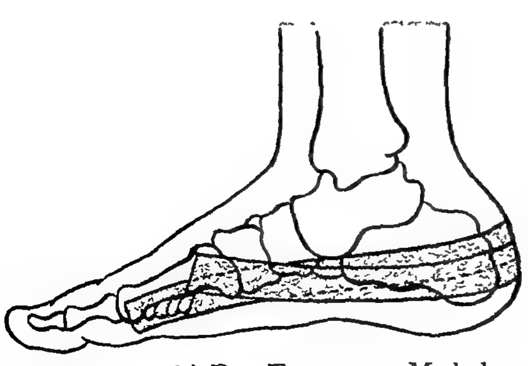
The imprint method fails to offer the accuracy that may be obtained from force gauges as developed by Burger; consequently, it is impossible to arrive at critical descriptions of weight distribution. The gross evaluation is, however, excellent for clinical purposes and, in instances of toe pressure areas, offers data that cannot be obtained with force gauge equipment.

DYE TECHINIQUE OF FLEXIBLE CASTING

Many adhesive taping techniques have been advanced which have as their intention a rest for the weak foot with all of its ligament relaxation and malalignment. The technique in adhesive strapping, developed by Dr. Ralph Dye, is a most effective form of foot rehabilitation It differs from the usual technique in that it aims at foot correction, not merely rest of a weak foot.

Dye bases his theory on Davis's Law, "Ligaments, or any soft tissues, when put under even a moderate degree of tension, if that tension is unremitting will elongate by addition of new material; on the contrary, when ligaments or soft tissues, remain uninterruptedly in a loose or relaxed state, they will gradually shorten, as the effete material is removed until they come to maintain the same relation to the body structure with which they are united that they did before shortening " On this basis, Dye casts the foot in flexible adhesive tapings until profound changes occur in the entire postural alignment of the individual. An over-developed group of peroneal muscles that have been aiding the foot to assume an abducted posture will gradually diminish in size as the foot is held in persistent adduction Even more dramatic reactions occur in other muscle groups as the leg rotates to an improved position. Continuous taping requires that meticulous care be given to the skin with proper cleansing and preparatory adherents.

Eight different strappings are listed by Dye, however, there are two basic castings that are used most frequently: the high taping that extends to the anterior leg muscles, and the low taping that is confined to the foot. Each strapping is designed to bring the foot into a normal position The drawing indicates the course of the tapings as related to the bony elements (Figs 371–378) Essentially, the calcaneus is pulled forward into an improved pitch, and drawn into



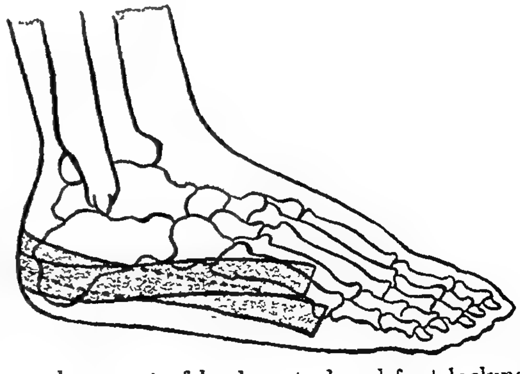


FIG 371 (Left) DYE TECHNIQUE Medial view placement of heel control and foot-locking straps

FIG. 372 (Right) DYE TECHNIQUE Lateral view heel straps applied below tendo achilles attachment and do not extend beyond metatarso-phalangeal joints

varus position. Other elements of the mid-tarsal joint organization fall into normal position. The tapes originating on the lateral side of the foot over the cuboid, crossing under the foot and attaching to the medial aspect on the dorsum, tend to rotate the cuboid into its proper alignment and to bind the transverse tarsal arch into normal position, thereby adjusting the forefoot into proper alignment. The tension on each strap is adjusted according to the degree of correction needed. The tension is increased as the case responds. Early treatments should be moderate. Rehabilitation requires several months in mild cases and as long as a year in severe cases. Dye contends that a foot is not rehabilitated until even the toes function properly.

Radiographic evaluation of the effectiveness of this taping has been made in many cases As a demonstration of the ability of this taping to realign the foot, "before and after" radiographs have been made in which extreme tension has been applied (Figs. 379, 380).

RADIOGRAPHIC PATTERNS FOR FOOT APPLIANCE PRESCRIPTION AND CONSTRUCTION

The conventional methods of prescribing foot appliances will be briefly reviewed so that the advantages and disadvantages may be considered, and a comparison made with the radiographic system.

Few doctors participate in the actual construction of foot appliances. The

FIG 380 SAME CASE AS FIG 379 Complete Dye Flexible Casting applied Note the following improvements (1) Talus parallel. (2) Sinus tarsi visible. (3) Medial arch on higher plane than lateral arch (4) Higher pitch of calcaneus (5) Fibula moved posteriorly in reference to tibia indicating foot inversion. (6) Talus more closely bound to calcaneus

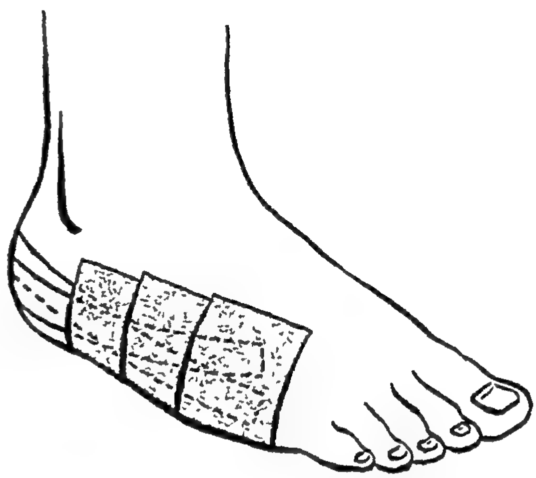


FIG. 377. (Left) DYE TECHNIQUE. Medial view: Rest strapping confined to foot. Adequate correction for moderate cases.

FIG. 378. (Right) DYE TECHNIQUE. Lateral view: Rest strapping. Note retention straps that support the foot-shape by binding the transverse arch. (Figs 371–378 from "Dye Technique of Foot Correction," courtesy of Dr. Ralph W Dye).

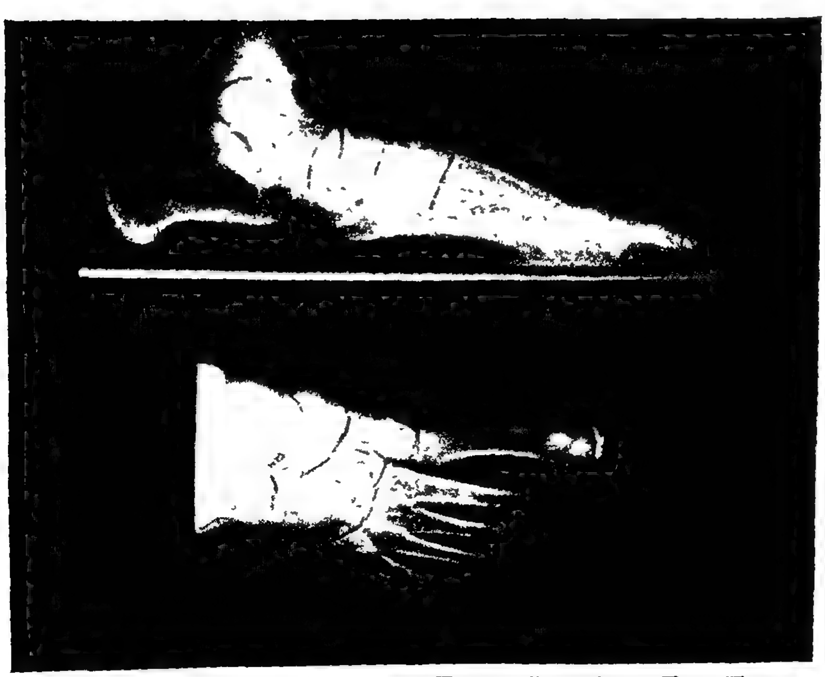


FIG 379 L W, SEVERE MID-TARSAL FAULT—LOW ARCH FOOT TYPE.

flesh outline of toe to the extreme of the flesh outline of the heel, because the x-ray beam sharply delineates these margins as it meets the film at both extremes; in fact, it is a sharper and more accurate outline than could be obtained by using a pencil because the lead is held at the pencil-wood thickness from the foot The bones within the outline are disposed in accurate position if the radiograph has been produced according to accurate image projection which is used in all standard positions. Soft tissue outlines are essential in this radiographic pattern; consequently, the exposure factors must be reduced enough to retain soft tissue, since a radiograph of bones would be of no value. When x-ray paper is used for this pattern, soft tissue outlines are easily assured X-ray paper has the distinct advantage of direct visualization without the need for transillumination. Furthermore, penciled markings may be easily charted on the paper radiograph. Both of these features facilitate handling of the prescription by the laboratory technician.

The additional information that may be added to the radiograph by employing the orthodynamic foot imprint is extremely advantageous. This adds a chart of the weight-force distribution so that the appliance may be designed to influence the foot to assume more specific patterns.

When specific areas require identification such as an idiopathic heloma on the plantar surface of the foot, a circular piece of lead foil may be cut to the exact size and shape and affixed over it so that it will be recorded on the radiograph as an area of opaqueness

Charting the Radiograph Pattern. There is an endless variety of foot appliance types, designed to influence the foot according to various theories. Although the radiograph may be used to evaluate the need of an appliance in practically all cases, the actual radiograph is not applicable as a pattern for all types A charting system will be described for those types of appliances that are known to utilize the radiograph as a pattern

Conventional Supportive Foot Appliance (Fig. 381)

(1) Outline the appliance shape with a skin or china marking pencil.

(a) The width of the forepart should be marked from the shaft of the first metatarsal, where it meets the contour of the head, to the shaft of the fifth metatarsal at its junction with the head of the bone. This width allows for the normal compression of the foot in a shoe so that the appliance will be compatible with the shoe width

(b) From the width marking on the fifth metatarsal, mark toward the heel to meet the flesh outline at the level of the cuboid bone and follow the flesh outline around the heel to the mid-tarsal joint where the flange-shape may be outlined as desired and curved back to meet the width mark on the first metatarsal

(c) Make a semi-circular line through the metatarsal joints to indicate the anterior margin of the appliance, and curve this line to meet the width lines.

majority prepare some form of pattern or mold and have a technician make the actual appliance. Some doctors do a certain amount of shoe modification work, and a limited number make plastic appliances that cannot be obtained from laboratories.

Models of the foot made of plaster of Paris, or other material, are frequently used as the pattern for an appliance. The model is sculptured to the degree and shape of correction desired in the appliance. This type of pattern is needed in making the Whitman Brace. Models made from impressions of the feet in repose in which the arch is accentuated and the eversion or inversion of the foot falls into its natural position are used for another type of appliance (developed by Bergman, Brachman, *et al.*) in which a balanced inlay is prepared. Models are advantageous in that all foot contours are present so that cupped heel-seats and other features may be accurately shaped. The Levy mold which aids toe flexion and all modifications such as Schuster's are made on plaster models

All of the dynamically molded foot appliances are produced without the aid of models, imprints, radiographs, or other charts, because the material is placed in the shoe and the foot shapes the appliance.

Pencil outlines of the foot borders are the basis of the simplest type of pattern. Markings for the first metatarso-phalangeal joint, the fifth metatarso-phalangeal joint, tuberosity of the navicular, and other landmarks are about all that is offered by this prescription. The data are very inadequate from a scientific standpoint

Imprints of the bearing surface of the foot were originated by Becker in an ingenious system of charting which utilizes stress formulae computed from points of the imprint and measurements of the foot. This is a valid scientific offering. Others have utilized imprint charts as a guide in appliance construction.

Elaborate methods have been devised of photographing the bottom of the foot in natural color so that pressure areas created by local ischemia provide a basis of designing the appliance. These systems are too expensive to be practical.

Attention is drawn to the fact that no accurate estimate of the structural pattern of the foot bones is available in any of the methods that have been described. Surface landmarks offer the only clue to the bony features.

Radiography of the foot has not received attention in the matter of foot appliance prescription because the usual dorso-plantar radiograph is not suitable for a pattern. The complete outline of the foot is lacking because of the superimposed shadows of the leg structure It is obvious that it would be impossible to make an appliance from this type of radiograph since no length dimension could be computed from the heel

An entirely new development is unfolded by consideration of the composite full-foot radiographic technique which has been described in the previous chapter. It consists of making a dorso-plantar view of the foot and, while the patient retains the same position, making a second exposure on the same film from the supero-posterior heel projection The combination of the two views superimposed on the same film provides an accurate profile of the entire foot, with the bony elements fully portrayed This foot radiograph is accurate from the tip of the

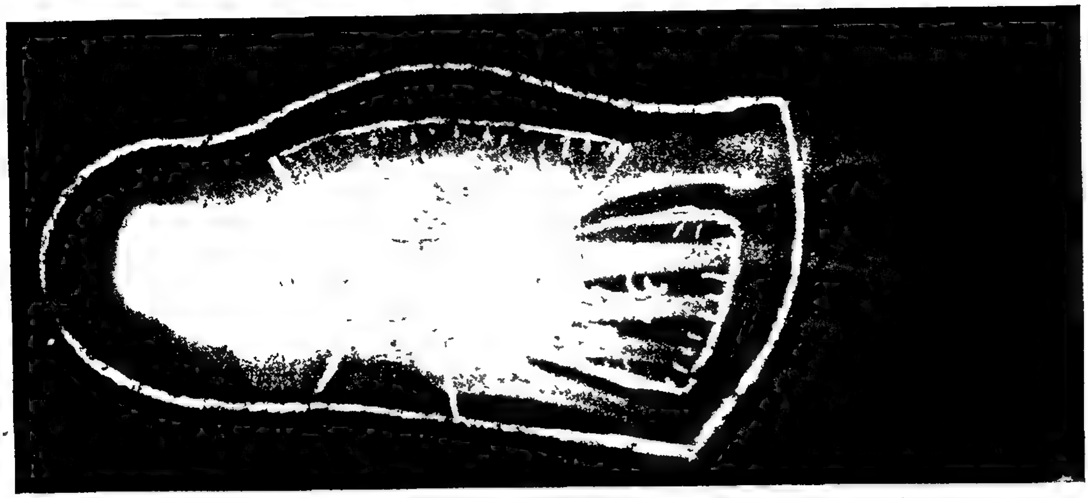


Fig 381 Radiograph Chart for Conventional Supportive Foot Appliance.

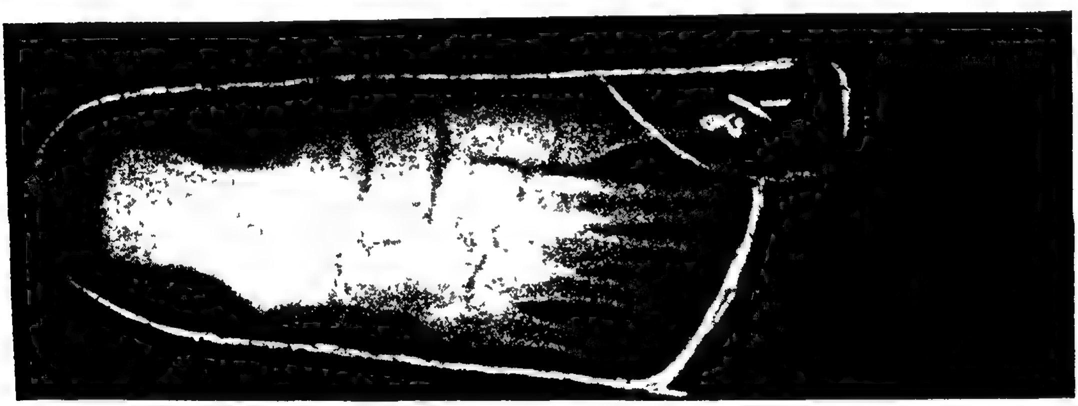


Fig. 382 Radiographic Chart for Compensating Insole (D J Morton principle)

Fig. 383 Radiographic Chart for Parabola Compensator (R Sansone Mold)

(2) Draw the correct shape metatarsal pad, according to the metatarsal condition, and shade in the highest point of elevation and mark the height of the elevation.
(3) Outline the shape of the longitudinal elevation desired and shade in the highest point of elevation with the elevation marked.
(4) Special features such as cuboid raises, bunion flanges, heel wedges, etc. should be drawn and marked.
(5) Mark spot relief cut-outs according to the location of opaque areas as marked by lead on the foot.

Compensating Insole (D. J. Morton) (Fig. 382)

(1) This appliance consists of a compensating innersole with an extension platform under the first metatarso-phalangeal area of about 1/8 in. in height. It is used in cases of shortness of the first metatarsal bone or hypermobility of the first metatarsal segment.
(2) Outline the foot following the width scheme from the first metatarsal shaft to the fifth metatarsal shaft, just in back of the head contours.
(3) Outline the distal end of the appliance by a mark through the metatarso-phalangeal joints.
(4) Extend a platform of a shape to include the first metatarso-phalangeal joint and the width of the first metatarsal head.
(5) Mark the height of the elevation.

Parabola Compensator (R Sansone Mold) (Fig. 383)

(1) This appliance utilizes Morton's principle of extending a platform under a short member, but does not restrict it to the first metatarsal; rather, any discrepancy in the metatarsal parabola is included in the compensation
(2) Outline the foot up to the metatarsal parabola.
(3) Draw extensions for each metatarsal segment that is deficient in length so that a platform may be made in the appliance to compensate for the inadequacy.

Bi-plane Appliance (Julius Becker)

(1) This appliance is designed to control the position of the calcaneus in much the same fashion as the Whitman brace, except that the leverage principle of the Whitman brace is supplanted by a fixed planing of the bottom of the appliance to maintain the corrected position of the calcaneus. The pressure lines of the top of the appliance conform to the needed correction as sculptured on the mold
(2) The appliance is molded from Celastic directly on a corrected model of the foot; consequently, the radiographic pattern is limited in its usefulness However, it does act as a pattern in preparing the size patterns for the Celastic blanks, and in determining accurately the position of the metatarso-phalangeal joints so that the appliance may be extended all the way under these joints according to Becker's concept of leverage extension of the toes.

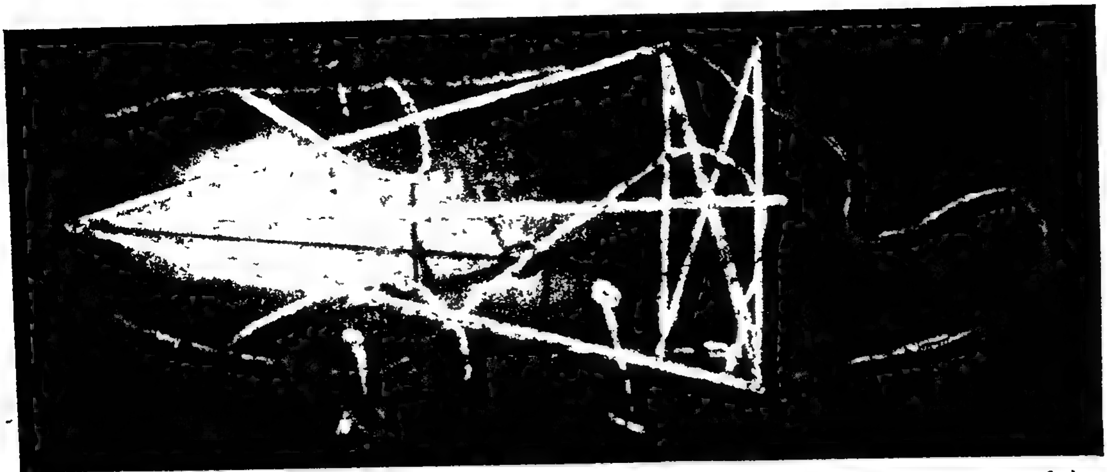
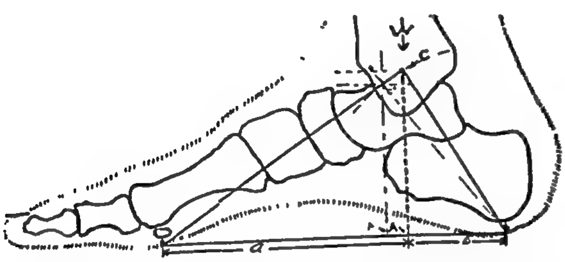


FIG 384 RADIOGRAPHIC CHART FOR TRI-WEDGE BALANCED APPLIANCE (Moss principle).



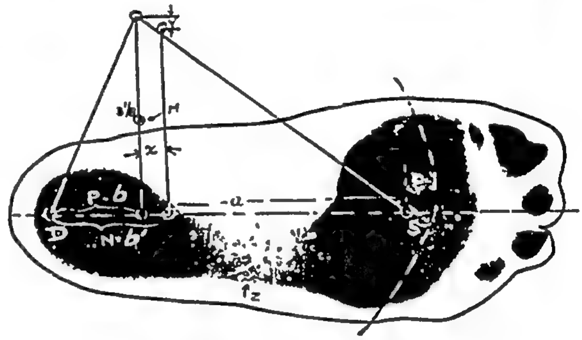


FIG. 385 RADIOGRAPHIC CHARTING FOR STRESS ANALYSIS. Used in constructing saddle-foot balancer (M. L. Becker principle)
FIG. 386 IMPRINT CHART USED IN CONSTRUCTING SADDLE-FOOT BALANCER (M L Becker principle) (Figs 385, 386 courtesy of Dr R. Becker)

radiograph and the foot imprint and the laboratory makes the chart and develops the interpretation (Figs. 385, 386).

(2) Becker offers a method of measuring the shoe length by drawing a line from the center of the heel through the foot to a point between the second and third metatarsals. A mark is made at the level of the head of the second metatarsal and a scale comparable to the Brannock heel-to-ball measurement is used to determine shoe size.

Compatible Appliances (L. H. Sherman)

(1) The method in which this appliance is constructed is unique. A sheet of Celastic is cut to a pattern from the flesh and metatarsal parabola outline of the foot radiograph Pin points may be carried through the radiograph to locate metatarsal corrective areas and marked on Celastic
(2) The Celastic is dipped in softener and then stuck to the bottom of the foot.
(3) Waxed paper is inserted in the shoe, and the foot is then fitted in the shoe and the patient instructed to walk The Celastic is thereby forced to take the shape of the foot in the shoe in a compatible manner.
(4) When the Celastic shell is removed from the shoe and allowed to harden, necessary modifications may be added according to foot needs and the radiographic chart location

Tri-wedge Balanced Appliance (Stanley Moss) (Fig. 384)

(1) The tri-wedge balanced appliance was developed by Moss as a result of his studying foot radiographs and devising a system of charting the the dorso-plantar full-foot view. A system of triangulation is used, and an attempt will be made to explain the features.

(2) A caliper is used from a centering point at the heel. A mark is made at the level of the center of the first metatarsal head. The caliper is turned to mark the same distance on a line extended through the fifth metatarsal head.

(3) The caliper is used from the centering point at the heel again to mark the level of the fifth metatarsal head; then, the caliper is turned to mark the same distance on the extended line from the first metatarsal head.

(4) The four points are joined by lines drawn crosswise from the fifth to the first metatarsal head levels.

(5) The center of the foot is represented where the cross lines intersect.

(6) A line drawn from the center of the heel to the center of the forefoot provides a means of appraising varus or valgus of the metatarsals and the subsequent need for a medial wedge to control the direction of weight-flow through the foot. This first wedge is outlined accordingly on the radiograph. The center line is the location for rib-steel reinforcement of the appliance.

(7) The second wedge is located from the center of the tuberosity of the navicular and extends under this bone and the sustentaculum tali with variable thickness.

(8) The third wedge is located from the base of the fifth metatarsal and extends under the cuboid bone with variable thickness.

(9) An arbitrary extension of approximately ⅛ in. is added to the heel length of the appliance to allow for displacement of the foot in the shoe.

(10) Shoe length is computed from the center of the heel to the mark representing the head of the first metatarsal.
Women. 6¼ = 4, 6½ = 5, 6¾ = 6, 7 = 7, 7¼ = 8, 7½ = 9, 7¾ = 10
Men: 6¾ = 5, 7 = 6, 7¼ = 7, 7½ = 8, 7¾ = 9, 8 = 10, 8¼ = 11

(11) Cut-outs are made in the forefoot wedge to accommodate spot relief areas that are marked on the radiograph by opaque areas as marked by lead on the foot.

(12) The distal margin of the appliance is marked by a curved line from the fifth metatarsal marking to the first metatarsal marking.

(13) Extended cushion under metatarso-phalangeal joints is designated by an outline the shape of the apron

(14) Other features may be added to the chart, such as flanges, to protect hallux valgus, etc.

Saddle Foot Balancer (M. L. Becker)

(1) The radiograph is utilized in the construction of this appliance in a very technical interpretation of stress diagrams that demonstrate the amount of change that has transpired in the foot The doctor supplies the lateral

Radiographs reveal some basic information concerning the position of the foot when shod that should be applied to any consideration of a foot problem.

Heel Height. (Figs. 387–392). Heel height places the foot in an unnatural position in which the foot is extended at the ankle and the toes are in extension with the metatarsal joints. Shortening of calf muscles and toe extensor muscles, with attendant foot problems, is the natural sequel to this faulty attitude. When a high heel is worn, the shank pitch conforms to the arch of the foot, and the wearer sometimes concludes that the foot is more comfortable in this type of heel than the lower one This is a false and transitory situation, for eventually muscles will become imbalanced and faulty posture will create a serious problem. The cowboy boot falls into the same category, except that the shape of the heel and its position under the mid-tarsal joint tends to improve the pitch of the calcaneus as the foot rolls over the heel in walking (Fig. 393)

Toe Shape. The toe shape of the shoe should be compatible with the toe shape of the foot (Figs 394, 395). The excrescence exploratory radiographic examination documents this relationship, and it should be the doctor's responsibility to advise the patient concerning any discrepancy of this order.

Last Shape. The last shape is designed to prepare a shoe for a foot of similar shape and dimensions It should be the doctor's responsibility to see that patients obtain shoes that are compatible with their general foot type. Short-toed feet require short vamp shoes, and feet that are long from ball to heel should be properly fitted on that score, etc. (Figs. 396, 397). The foot cannot function freely if it must fight an incompatible shoe.

Feature Shoes. Shoes are produced that incorporate construction features that are designed to influence the foot, such as medial heel wedges, arch build-ups, and metatarsal pads (Fig. 398). Shoes of this type that are produced by production line procedures are not specific enough to satisfy varying foot conditions. The features have more sales appeal than validity. Shoe fitters are incompetent to diagnose foot conditions and should not be permitted to foist upon the unsuspecting public shoes that they claim will improve foot problems. The enlightened shoe fitter may be the doctor's best ally in providing the proper shoe and rendering a proper fitting, according to the doctor's radiographic appraisal of the foot (Figs. 399, 400). Shoe manufacturers have produced a variety of lasts that provide shoes for practically any foot type, and the shoe fitter and doctor working together may better serve the patient

Custom Shoes Custom shoes may be made for specific foot problems according to conventional shoe construction methods It is wise to provide radiographs of the foot deformity in question so that the shoemaker may fully appreciate the problem (Fig 401).

Molded Shoes Shoes that are molded over a high fidelity plaster model of the foot have been introduced by Murray. Many claims have been propounded which reach panacea proportions This type of shoe presents advantages; however, it has limitations (Figs 402–404). Physiologically, the ridge that is formed in the shoe beneath the toes provides an area over which the toes may make purchase. This keeps the intrinsic foot muscles active and thereby strengthens the foot. If the shoe is made to the exact dimension of the foot held in semi-weight-bearing position, there is no room for the foot to elongate, even to a

(5) Materials other than Celastic may be used with the Sherman compatible method.

Shoe Modifications with Cement-in-pads.

(1) The shape of the appliance may be cut from the radiographic pattern, especially x-ray paper, and the various build-ups located by cutting out the shapes desired.
(2) This x-ray paper stencil is then inserted into the shoe and the cut-out shapes marked with indelible pencil so that the build-ups may be placed in accurate position.

Utilizing the X-Ray Paper Radiograph in Actual Construction

(1) The shape of the appliance may be cut from the radiographic outline, and then this pattern may be soaked in water until the backing is saturated. The emulsion side may be peeled off along a thin layer of paper and allowed to dry under a weighted blotter.
(2) The thin paper pattern may be cemented into the shoe and the modifications applied directly in place on the bone outlines.
(3) The thin paper pattern may be cemented on a celastic or leather shell and the modifications applied in proper place prior to affixing the top cover of the appliance.

Advice to Bracemaker. In order to produce an effective appliance it is necessary in every case for the technician to have some basic information about the case. The following are routine factors to be considered: the weight of the patient, whether the foot is flaccid or spastic, the type of shoe into which the appliance will be fitted, heel height, and shoe size. A note specifying the type of material, and the density of the modifications is imperative Additional information concerning the case in regard to the occupational factors involved and any other pertinent data may help the technician choose suitable weight materials for the appliance

Some laboratories require a special data chart to be completed and sent with each case

If the doctor expects the laboratory to produce good work, he should cooperate in the fullest to gain the end result.

RADIOGRAPHY OF FOOTGEAR

Shoes should primarily provide a protective covering for the foot. In order to protect the foot from abuse, a shoe should be able to cope with the work pattern and environment in which the individual operates Some shoes are made for adornment Unfortunately, shoes that are made for adornment usually fail to qualify as shoes of adequate protection Shoes are made in an untold variety of shapes and construction features

Carleton emphasizes the need for the doctor to have an appreciation of the relationship of shoes to feet It is necessary in order to achieve good results in treatment The very strong normal foot may be able to function adequately in spite of foot-covering, however, the problem foot requires the most acceptable shoe.

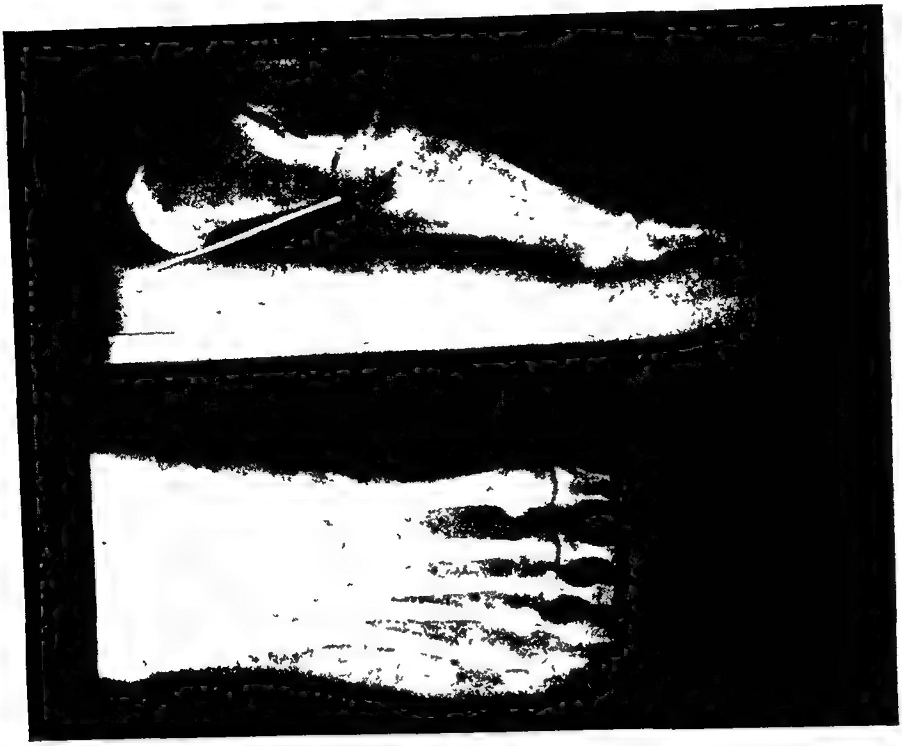


FIG. 389. $1\frac{0}{8}$ in Heel Height Molded Shoe—16° Pitch of Calcaneus with Standing Surface.

FIG. 390 $1\frac{2}{8}$ in Heel Height—7° Pitch of Calcaneus with Standing Surface Note shank placement

Figs. 387–392. Series Depicting the Same Foot Structure in Various Heel-Height Shoes

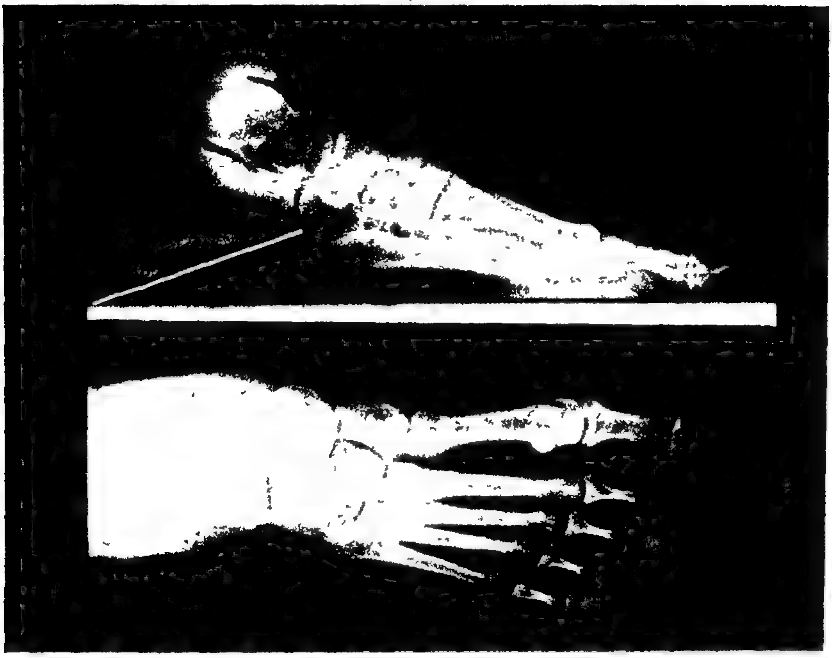


Fig 387 Foot Unshod—Normal Medium Height Arch Type 16° pitch of calcaneus with standing surface

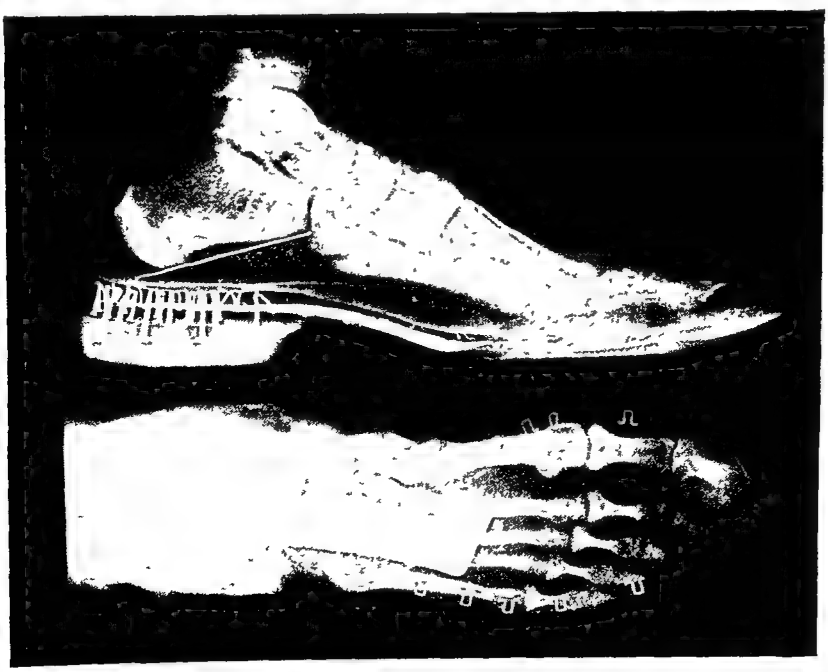


Fig 388 ⅝ in Heel Height—14° Pitch of Calcaneus with Standing Surface

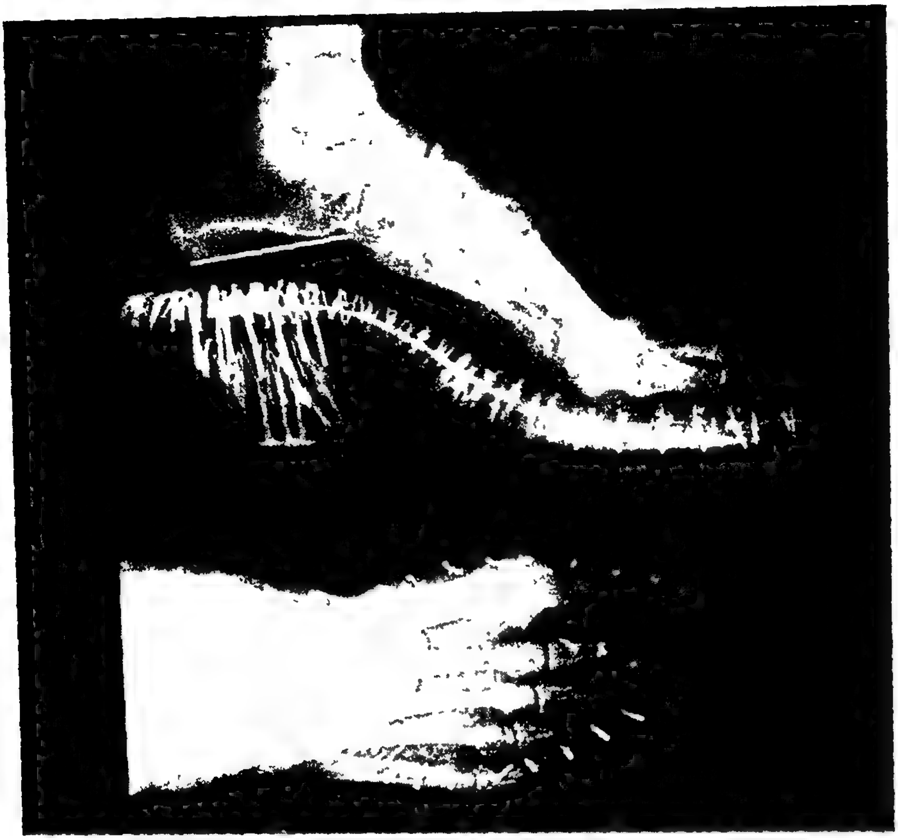


Fig. 393. Foot Shod in Cowboy Boot. Note boot-heel placement in relation to pitch of calcaneus Mid-tarsal fault in spite of lifetime use of boot Toe shape is atrocious Traumatic degenerative arthritis of first metatarso-phalangeal joint—tramped by horse.

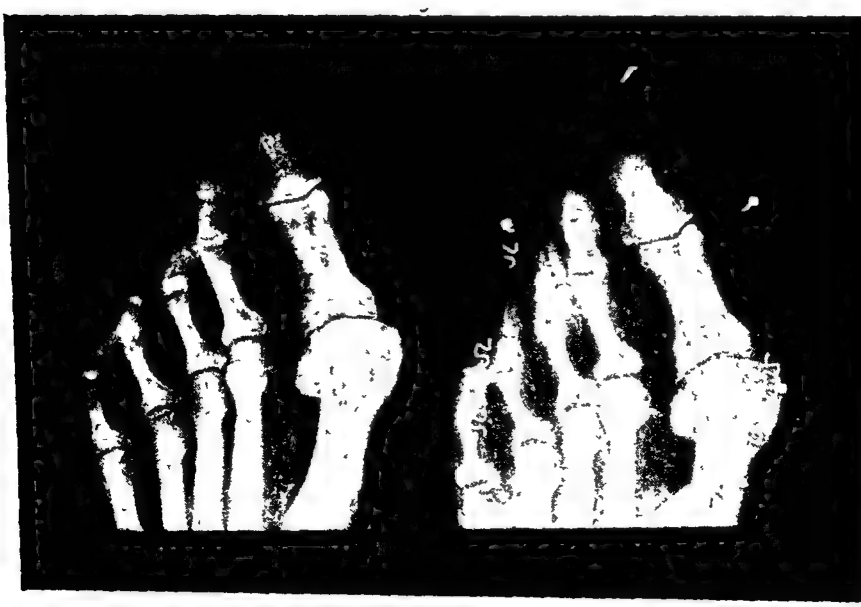


Fig. 394. Compatible Toe Shape. Adequate room for hallux valgus problem and lesser toes.

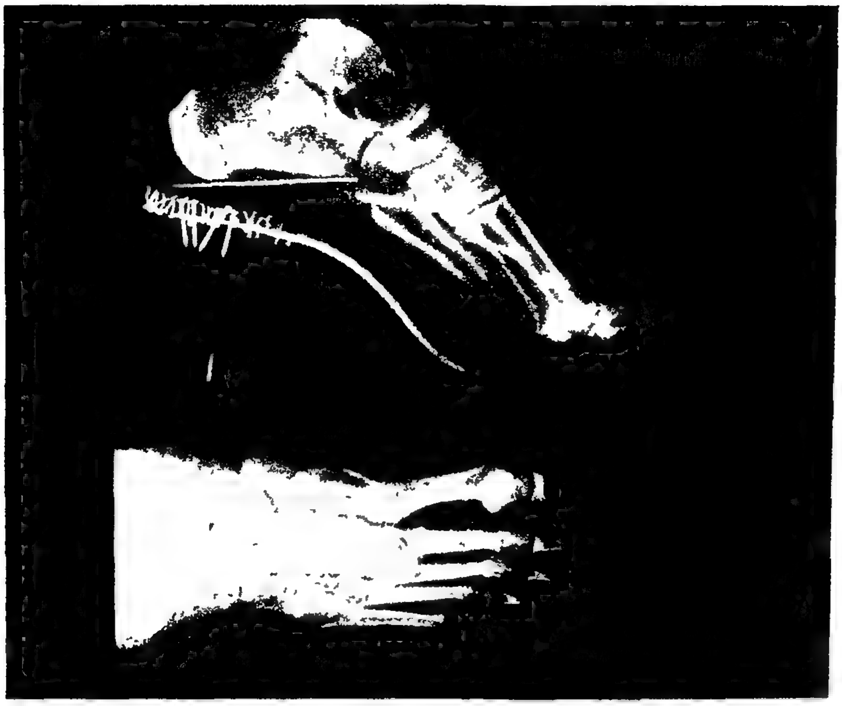


FIG. 391 1⅝ in Heel Height—3° Pitch of Calcaneus with Standing Surface. Note foot extension at ankle with weight forces received through posterior crown of talus.

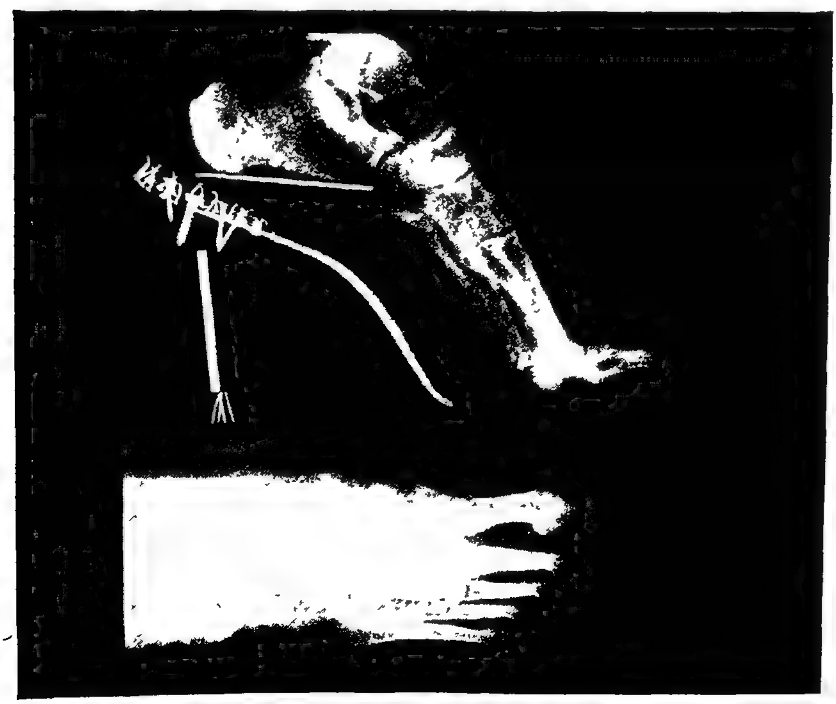


FIG. 392. 2⅛ in Heel Height—Minus 4° Pitch of Calcaneus with Standing Surface. Note toe extension, and distorted bone shapes in dorso-plantar view

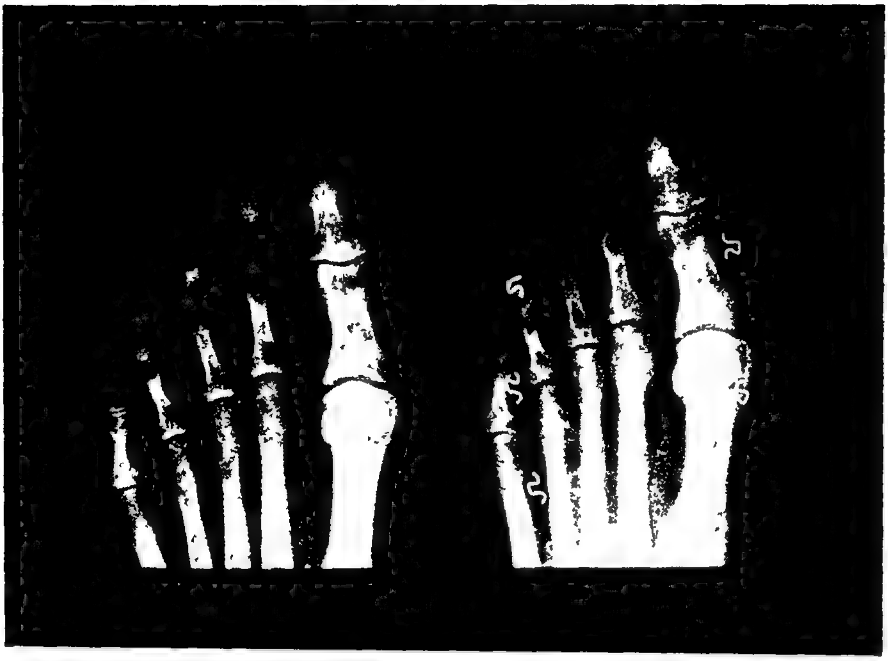


FIG 397. INCOMPATIBLE LAST SHAPE Long toes—short vamp.

FIG. 398 SHOE CONSTRUCTION FEATURE Metal metatarsal form adjustable postero-distally but not lateral-wise

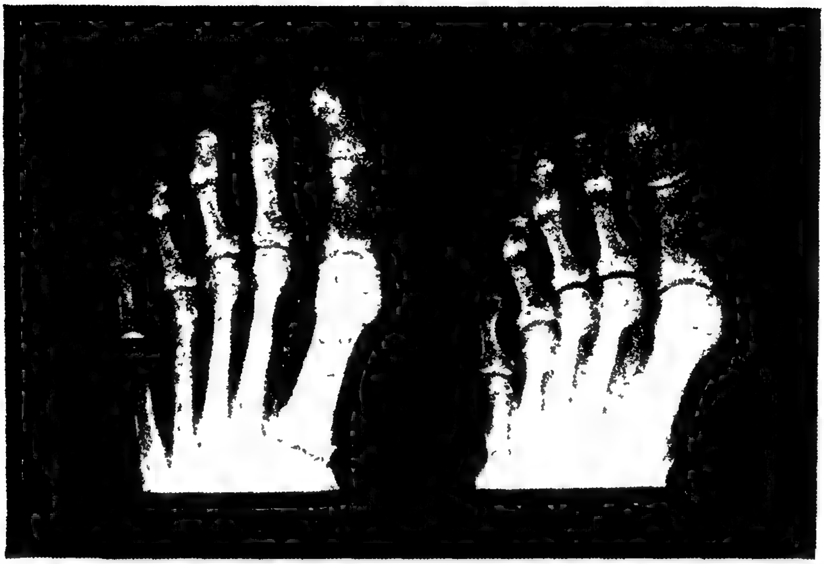


FIG. 395. INCOMPATIBLE SHOE TOE-SHAPE. Blunt-shaped toe outline forced in a too pointed toe-shape Note heloma molle marked with radio-opaque medium.

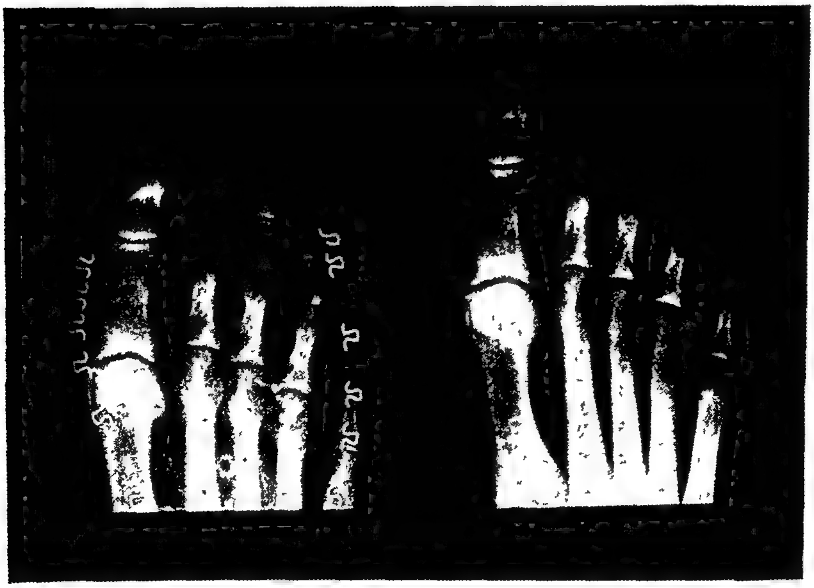


FIG. 396. COMPATIBLE LAST SHAPE. Long toes—long vamp.

Fig. 401 Radiograph Discloses Findings That Will Influence Custom Shoe Prescription and Construction

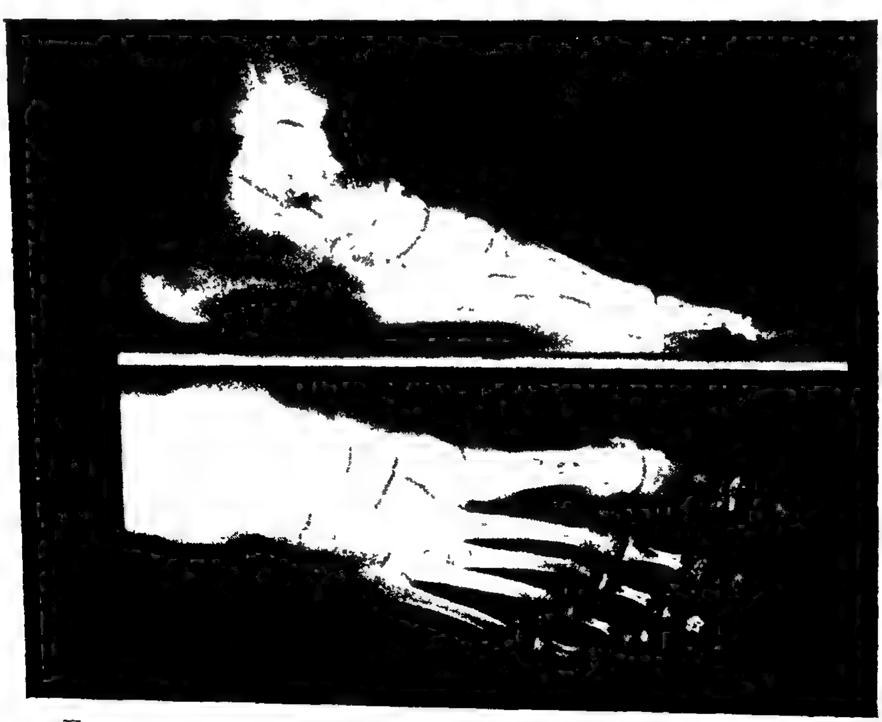


Fig 402 Foot Unshod Normal Medium-height Arch Type

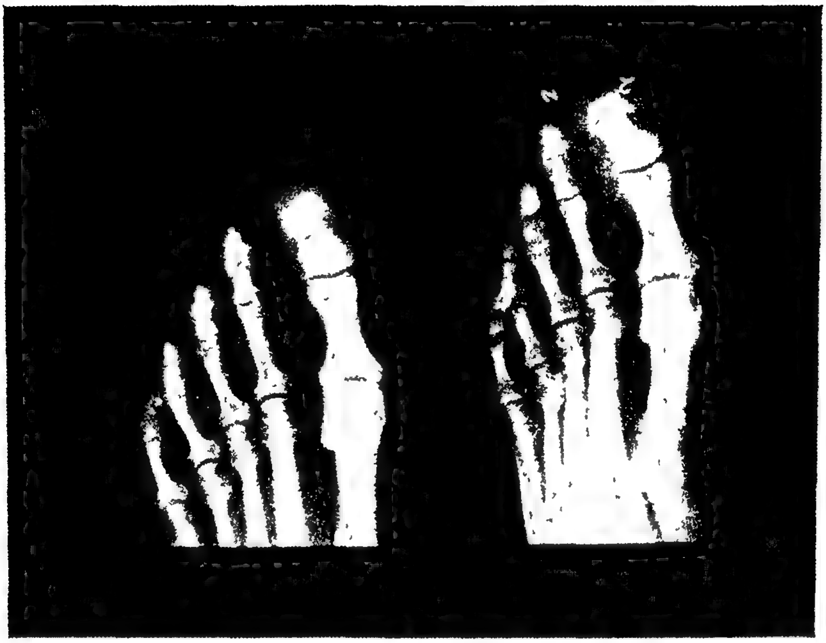


FIG 399. INCOMPATIBLE FITTING Shoe too tight.

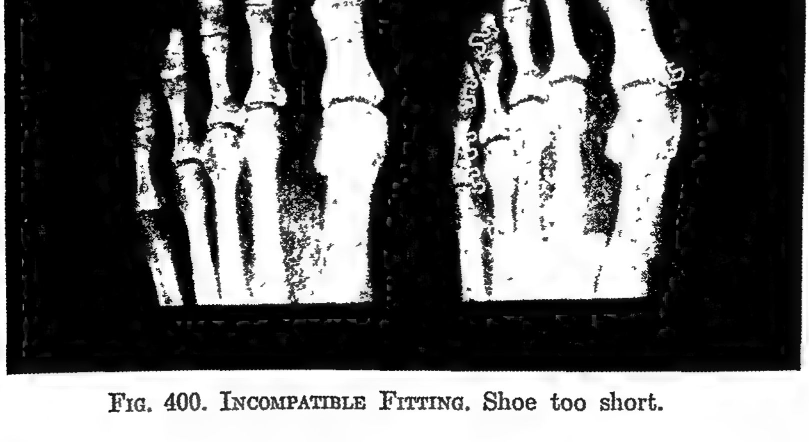


FIG. 400. INCOMPATIBLE FITTING. Shoe too short.

normal physiological limit of joint excursion; consequently, the wearer must hold the foot in a contracted position to avoid pressure against the end of the shoe. This sequence of changed foot posture tends to improve a foot that has acquired faults, although it is an uncomfortable process of acquiring the gain. Radiographs of the shod foot demonstrate the restrictive capacity of the shoe. Additional room in front of the great toe makes for a more comfortable shoe, although some of the corrective action may be lost. The lack of free space minimizes frictional areas so that the molded shoe provides an ideal foot covering for the arthritic foot and other deformed feet. Every plantar contour is accommodated—a factor of great comfort to the wearer.

RADIOGRAPHIC EVALUATION OF ORTHODIGITAL DEVICES

Polokoff has devised orthodigital pads of felt and Latex to meet practically every problem. A basic double ring pad is used to straighten contracted toes. It consists of a piece of ¼ in. felt that is folded and cut in such a manner as to provide a circle around the fifth and second toes, while a bar of double bulk fits under the toes to raise the distal portion in a straightening manner. A simplified version is made with the surgitube (Figs. 405, 406) Radiographs show the "before and after" effect of the pad (Figs 407, 408). A period of from two months to a year may be necessary to gain the desired effect

The author has modified Polokoff's pad for use in contracted arthritic toes. A felt pad (¼ in.) is used and three holes are fashioned so that the pad may be slipped over the toes with a separating partition of felt between each toe to encourage action of the interossei A wedge of felt is built up to fit under the toes by adding tapered pieces of felt to the basic blank with Mason's Cedar Plaster A piece of moleskin may be used to bind the wedge together more durably. Although the toes of the arthritic may not be materially straightened, an improved sense of balance is gained because the short toe flexor muscles become effective whereas, before application of the purchase pad, the long toe flexors drew the toes back into the foot with imbalanced action.

All types of wedge purchase pads under the toes have the effect of relieving lesions under the metatarsal heads because the toes are enlisted in a weight-bearing function.

Excrescences on the distal ends of the toes are benefited by the toe straightening, and lesions on the dorsum likewise are relieved.

When a modicum of correction has been obtained with the felt device, a retainer may be made of flexible plastic after the methods of Kempf and Conley (Fig 409). The plastic device is far more effective than the crest that is provided in molded shoes or the Levy-Schuster mold, because it actually fits the sulcus beneath and between the toes Furthermore, it may be worn in standard shoes.

DETERMINING THE NEED FOR THE BRACHMAN TALIPES SPLINT BY RADIOGRAPHY

Brachman has devised an aluminum bar-type splint that is affixed to the shoes of an infant to be worn as a night splint or during daytime as ambulatory "skates" The device is prescribed for four basic conditions: talipes equino varus, calcaneo valgus, talipes equino valgus, and cerebral palsy problems.

Determination of foot bone alignment and the need for the splint is made [illegible] foot radiographs (Figs 410, 411).

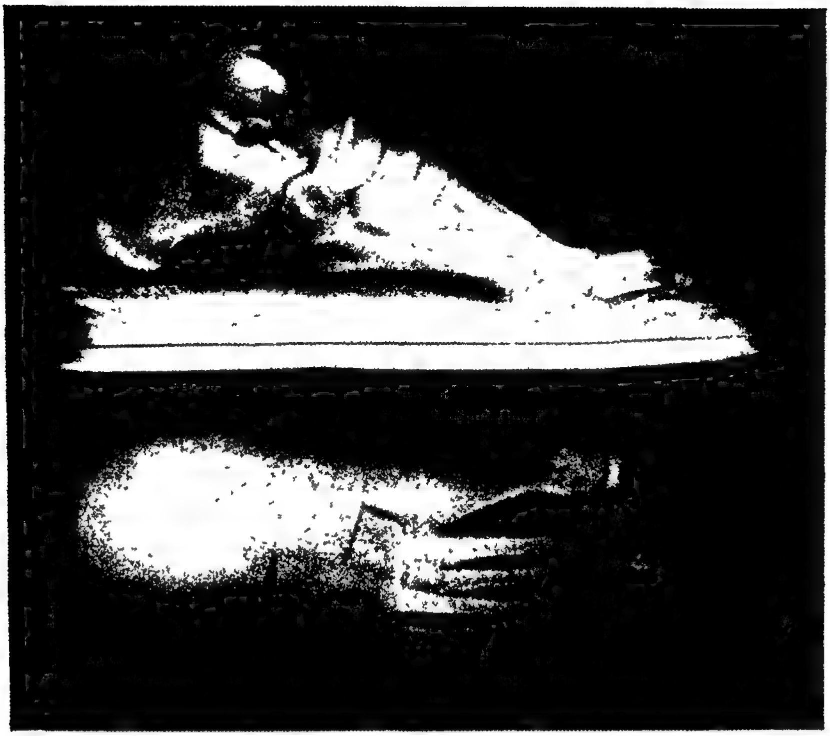


FIG. 403. SAME CASE AS FIG. 402 Foot shod in Murray molded shoe Note widened sinus tarsi indicating *foot inversion, contour under toes, flexed distal phalanges of second and third toes,* and close fitting to toe length

FIG. 404. SAME CASE AS FIG. 402. Foot shod in conventional shoe with tri-wedge appliance applied Compare with Fig. 403.

FIG 407 SAME CASE AS FIG 405 Radiograph of contracted toe prior to application of orthodigital pad Note overlap of phalanges and lack of joint space

FIG 405 PHOTOGRAPH OF POLOKOFF ORTHODIGITAL PAD Made with felt toe straightener enclosed in surgitube Note contracted third toes. (Plantar view)

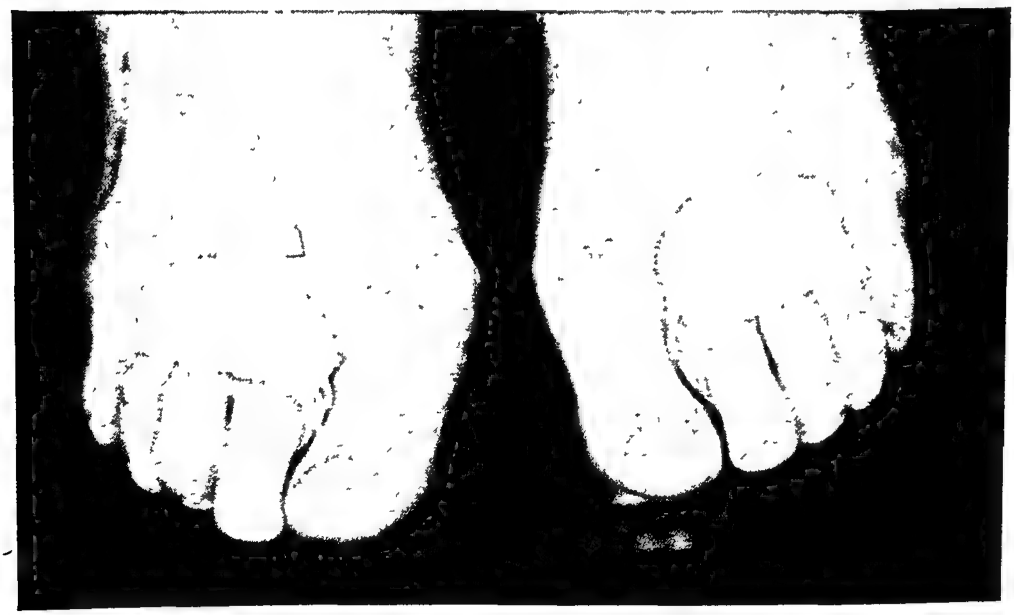


FIG 406 SAME CASE AS FIG 405 Dorsal view of Polokoff orthodigital pad

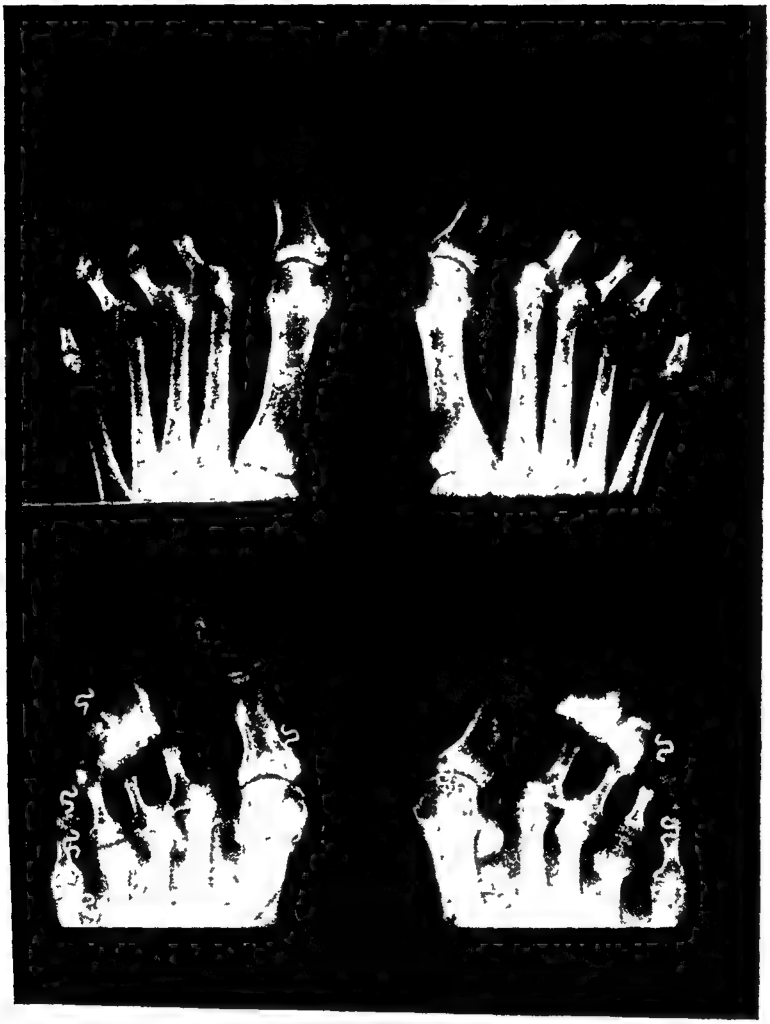


FIG 409 RADIOGRAPH OF RHEUMATOID ARTHRITIC CASE Observe particularly the metatarso-phalangeal subluxations of the second and third toes of left foot The lower section shows the same case shod and a flexible plastic toe retainer applied to assist in toe purchase. Note the improvement in the second and third metatarso-phalangeal joints of left foot The flexible plastic toe retainer is visualized as an area of increased density under the interphalangeal joints.

FIG. 408. SAME CASE AND TOE AS FIG 407 Radiograph of toe straightened by application of orthodigital pad. Note lack of overlap of phalanges, and improved joint space.

(Figs. 405–408 courtesy of Dr. A. K. Whitney)

RADIOGRAPHY OF THE FOOT OF THE PREGNANT WOMAN

The foot practitioner is well aware of the frequent breakdown of the foot during pregnancy. Schwartz has followed the clinical course of 18 cases of pregnant women with the conclusion that it is a factor in causing painful feet and pains in the "lumbo-sacral" and "sacro-iliac" region. An increase in weight of from 17 to 40 pounds, plus the fact that the added weight comes in the last trimester of pregnancy are the significant etiological factors. Back symptoms came only after the third and fourth month, before the greatest weight increase, and continued after delivery. The adjustment of the entire skeletal alignment is, of course, the basis for the problem.

Radiographs of the foot taken early during the pregnancy and near term will disclose incipient foot weakness Greater cooperation between obstetrician and foot specialist is imperative for the benefit of the patient.

The young mother, recently converted from a carefree existence or sedentary job to the manifold duties of the household including lifting and carrying the baby through several years of childhood, should be warned that foot care is a very important issue in maintaining good posture, good feet and good health.

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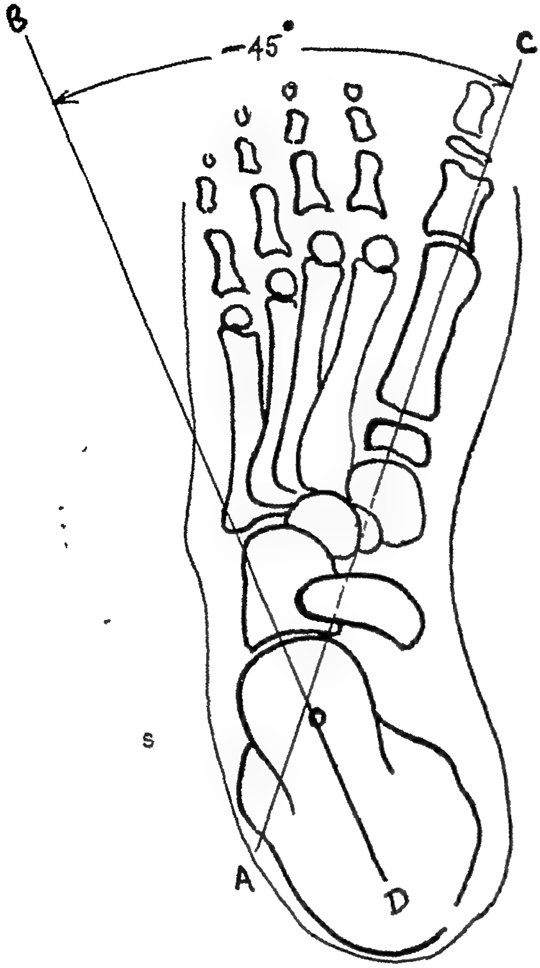

Fig. 410 Relationship of Bones in the Foot of a Six-year-old with Talipes Equino Varus Dorso-plantar view Whenever angle BOC is less than 0°, the foot must be considered within the range of a varus deformity This angulation of minus 45° is a severe type of varus deformity.

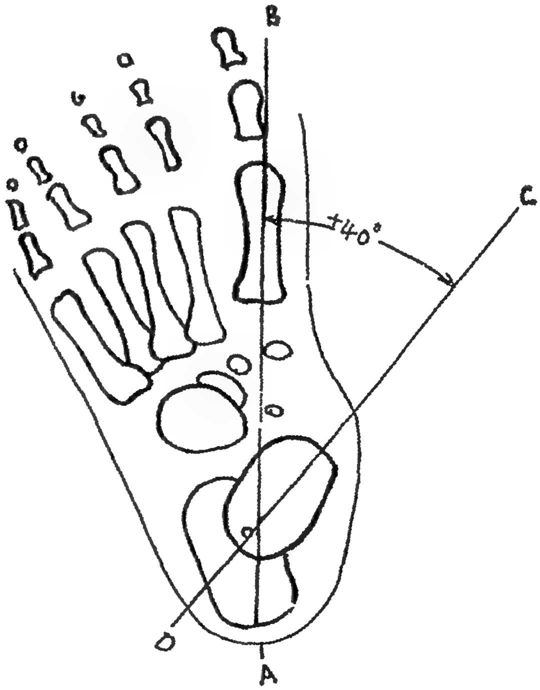

Fig 411 Relationship of Bones in the Foot of a Six-year-old with a calcaneo valgus type foot Dorso-plantar view Whenever BOC is greater than plus 25°, we must consider the foot in the range of valgus deformity This angulation of plus 40° is a moderate-severe type of valgus deformity (Figs 410, 411 courtesy of Dr. P. R Brachman)

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